L OF GRADUATE STUDIES

CLIMATE CHANGE AND HEAT WAVES: THEIR IMPLICATIONS ON CARE HOMES IN THE UNITED KINGDOM

by

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Abstract

With strong scientific evidence that climate change is a reality and that the average temperature within the coming century will increase by several degrees, it is essential to assess the extent to which this increase in temperature will affect the occurrence of summertime thermal discomfort and overheating in buildings in the United Kingdom. Although previous research has been carried out regarding the impacts of climate change on buildings, the studies generally considered the relationship between climate change and thermal discomfort. However, the catastrophic heatwave which occurred in France during the summer of 2003, which caused a very large number of deaths, a majority of these being amongst the elderly portion of the population who were residing in care home institutions, raised a number of questions and consequently, a need to relate projected future high temperatures with mortality. This report attempts to analyse how the building features and structure of care homes can be modified to better adapt to climate change, using passive means of cooling as far as possible. For this to be achieved, projected climatic data were created, based on existing data and the UKCIP02 climate change scenarios for the three future time-series: 2020's, 2050's and 2080's. These projected climate data files were then applied to a care home case-study model using TAS thermal simulation software so as to assess overheating in the future. The design features of the building were also considered to assess the extent to which they are related to summertime overheating, and how they can be improved to reduce or control overheating. Passive cooling strategies were then applied to the building with the aim of investigating their efficiency in reducing or controlling summertime overheating and preventing heat-related mortality from occurring in the future. Based on the results of the simulations, the percentage of time during which the temperatures can be maintained within safe limits via passive methods was estimated.

Europe has experienced an unprecedented rate of warming in recent decades (Klein *et al.*, 2002). The number of episodes of extreme temperatures each year has increased twice as fast as was expected, as opposed to a reduction in periods of extreme cold. The frequency of very hot days in England has increased since the 1960s, the summer period in 1976, 1983, 1990 and 1995 being extremely hot ones. Consistently hot periods have become more frequent, particularly in May and July (Hulme *et al.*, 2002).

During the months of July and August 2003, significantly high temperatures were observed throughout Europe, Scandinavia, and western Russia, with monthly mean temperatures exceeding the 90th percentile in each region (WHO, 2003). Kovats *et al.* (2004) have estimated that England and Wales experienced an extra 2,045 deaths (16% increase) between the period 4-13th August, 2003. The impacts that this catastrophe had on human health, particularly in France, raised several questions about the problem. According to current predictions on climate change, more extreme climatic events such as heat waves and floods are likely to occur in coming years, and the frequency and duration of these events are predicted to be more severe.

The period 4th to 12th of August 2003 was exceptional in the meteorological history of Paris (Institut de Veille Sanitaire, 2003), due to its intensity and duration as well as the minimum and maximum daily temperatures, which were the highest measured since 1873. According to the 'Institut de Veille Sanitaire' in France, an estimated excess mortality of 11,435 people occurred during the period 1st to 15th August. Other countries, including Germany, Italy, Spain and the United Kingdom were also affected, and the events of August 2003 have shown that the effects of heat-waves were largely underestimated.

The impacts of the heat wave on health, especially in France, caused a lot of debate. For instance, what are the consequences of heat waves on human health; can heat-wave impacts be prevented and, if so, how? Studies have been consequently carried out on the 2003 heat wave in Europe, the results of which are important for the future, in particular to identify cost-effective measures of prevention and intervention, as current predictions in climate change clearly show that extreme weather events such as heat waves will occur at more frequent intervals and with greater severity in the future.

The aim of this report is to address the question of how climate change, and especially periods of extreme heat, will affect the internal environment in care homes and the extent to which it will influence mortality rate amongst their residents. The report also looks at how effective passive strategies can be in reducing the risk of overheating in care homes, and how the effectiveness of these strategies varies under the changing climate. For this to be achieved, projections into the future climate have first been made, so as to provide an estimate of the extent to which temperature will rise within this century. Dynamic thermal modelling was then used to assess the internal conditions in a case study care home model under the changing climate.

A core part of this study is to analyse the performance of passive design features and cooling strategies in keeping the internal conditions within safe limits, without having to use mechanical means of cooling. The passive strategies which have been investigates are: the control of solar radiation through proper shading, the use of natural ventilation, and the use of thermal mass in conjunction with night purge. These strategies have been applied to the case study model, which has been tested under actual and future climates.

The structure of the document, following the introduction, is as follows:

Chapter 2 gives a review of the impacts of heatwaves on mortality, especially the heatwave occurring in France during the summer of 2003, which caused a very rate of mortality amongst the elderly. This chapter also looks at why overheating in care homes should be given special attention and what preventive measures can be taken to minimise the risks of heat-related deaths. The relationship between mortality and heat has also been considered, and estimated 'safe' temperature limits have been estimated.

Chapter 3 describes the climate change scenarios which have been used and details the method used to create projected climate data.

Chapter 4 gives and overview of the projected climate data, particularly emphasising the increase in temperature which will occur within this century.

Chapter 5 gives details of the model used as a case-study and the results of the dynamic thermal modelling under present and future climate.

Chapter 6 analyses the performance of the passive strategies and design features that have been used to control overheating. The effectiveness of the strategies have been compared under the different future climate scenarios.

Chapter 7 illustrates the extent to which overheating occurs in the care home model under the future climates, based on the 'safe' temperature limits defined in Chapter 2.

2. Literature review

2.1 France: high mortality during the 2003 heat wave

In the first two weeks of August 2003, France experienced an unusual heat wave. The month began with a dry sunny weather and temperatures above 30 °C, which is higher than the average of 25 °C for this time of the year. According to Ogg (2005), by the 4th of August, temperatures above 35°C were recorded in two-thirds of meteorological sites, and above 40°C in 15% of these sites. For the following nine days, day time temperatures averaged around 36 °C and 37 °C and in some areas night time temperature did not descend below 24°C. The period between the 4th and the 14th of August is now known to have been the '*longest sequence of consecutive hot days in the French meteorological history*' (Lagadec, 2004).

The 2003 heat wave had three main characteristics which in combination make it an extraordinary climatic phenomenon. Firstly, higher than average mean temperatures were recorded through many parts of France; secondly, there was a small difference between day and night temperatures for successive days; and thirdly, both of these trends happened over a prolonged period of time. Combined with other factors such as high pollution levels in cities, absence of air condition or inadequate ventilation in homes and institutions, caused a highly atypical number of deaths during that period. Research carried out by Institut national de la santé et de la recherche médicale (INSERM) (Hémon et al., 2003) showed that an estimated 56,500 people died in August 2003, which is about 15,000 higher than the average 41,300 deaths recorded in August 2000, 2001 and 2002 in France. Results from the research carried out by INSERM showed that the month of August displayed mortality rates well above the average, as shown in Figure 1. High mortality rates were also observed in the summers of 1975 and 1983 in France, yet not to the extent of the 2003 heat wave.

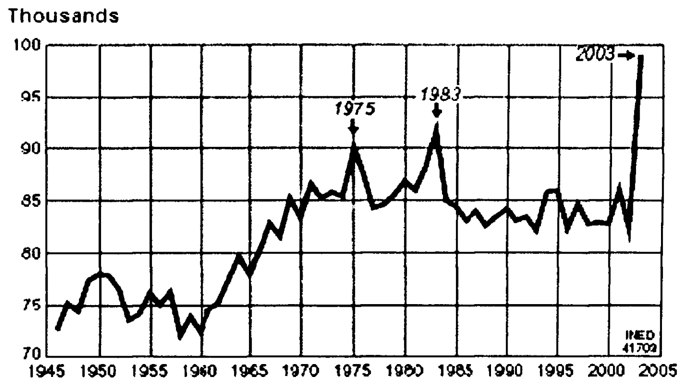


Figure 1: Number of deaths in France during the months of July and August between 1946 and 2003. Source: Hémon and Jougla (2003)

As the heat wave persevered, it gradually became clear that there was a link between the unusually high temperatures and a larger than average number of deaths. It was also found that the majority of deaths were occurring among the elderly segment of the population, with casualties occurring in retirement homes and other institutions as well as in private houses and flats.

The 'urban heat island effect' (UHI), which refers to the fact that inner city urban areas register higher heat indices than suburbs or rural areas (Moreno-Garcia 1994), appeared to be related to the high mortality rates during heat waves. Cities in temperate climates that experience a heat wave tend to be more vulnerable to adverse consequences than cities that are habitually used to high temperatures (Ogg, 2005). This seemed to be the case during the 2003 heat wave not only in France, where Paris experienced more victims than Marseille, but also in Italy, where the heat wave caused a larger number of deaths among the elderly deaths in north-western cities than in southern Italy (Conti *et al.*, 2004).

Results from the research also suggested that the architectural design and housing were related to the mortalities caused by the French heat wave. One striking aspect is the fact that many deaths occurred in care homes and other institutions. Although poor staffing levels have first been attributed as a significant factor contributing to the deaths, the design of the buildings has also been brought into question. The Laroque report (Leger *et al.*, 2004) published in January 2004, referred to a lack of air conditioning in many of the affected care homes, which is believed to have contributed to the dehydration of residents. The report also concluded that in institutions which had no air conditioning and yet were least affected by high death rates, the building layout tended to have rooms spread out over a large plan area and did not include many large windows. Although windows can be useful in providing adequate natural ventilation into a building, a compromise has to be made between the size and the number of window openings. The larger the windows, the greater will be the solar heat gains; therefore adequate shading should be provided to ensure that solar heat gains are minimised.

2.2 Overheating in care homes

"Extreme heat is dangerous to everyone, especially older people, and especially those living in care homes. During a heat wave, when temperatures remain abnormally high over more than a couple of days, it can prove fatal. Climate change means heat waves are likely to become more common in England. In one hot nine day spell in South East England in August 2003, there were nearly 2000 extra deaths. The biggest increase in risk of death was among those in care homes" (Department of Health, 2006).

It is therefore important that precautions are taken to minimise risks of overheating in care homes. Studies carried out by the Institut de Veille Sanitaire (2004) after the August 2003 heat wave showed that the quality of the building was related to the number of deaths in care homes. The factors that were found to relate most to overheating were, amongst others, the number of storeys, insulation, construction materials, size/number of rooms, glazing ratio and the amount of natural or mechanical ventilation.

The statistical results published in the 2004 report by the Institut de Veille Sanitaire showed that buildings constructed before 1975 and in which no renovation work has been carried out on the insulation, revealed higher mortality rates during the heat wave. It also showed that there was higher mortality in buildings which allowed for no proper ventilation between the rooms or made no use of air-conditioning. Lastly, the report revealed that buildings consisting of large areas of glazing, whether shaded or not, entailed higher mortality.

2.3 Preventive measures

As a consequence of the high mortality rates associated with the heat wave in 2003 in France, the *Système d'alerte canicule et santé 2004* (SACS 2004) was set up, the aim of which was to warn public authorities of a possible forthcoming heat wave, to allow them to better anticipate this phenomenon and advise people about the associated risks and appropriate preventive measures. It was also suggested that all care homes have at least one cool room available and have a coordination system set up in case of a heat wave emergency. The government announced in 2004 that it would meet up to 40% of the costs of purchasing air conditioners for rooms in care homes. In July 2005, the Ministry of Health in France reported that 90% of establishments for older people were equipped with at least one 'cool room' and that 81% have all the measures in place to launch the 'blue plan' in case of a further heat wave, as compared to only 18.5% in 2003 (Ogg, 2005).

In May 2004, the Government announced the 'Heat wave Plan', in which 'vigilance', 'surveillance' and 'prevention' are the key aspects. The plan includes definitions of heat levels to identify different types of situations by their potential gravity: *vigilance, alert, intervention*, and *mobilisation*. The French Meteorological Office also set up a 'daily heat check', ensuring that it can rapidly pass on information to the Ministry of Public Health.

The French heat wave which occurred during August 2003 raised a number of issues, some of which directly concern elderly people, for instance, community care and the quality of life in nursing and residential homes. These issues are relevant for all societies, especially countries which are in more temperate zones than France, such as the UK. It is therefore important to address the implications of the 2003 French heat wave crisis for the UK.

Although a heat wave of the scale of that occurring in 2003 is statistically unusual, climatologists have put forward that *'the European summer climate might experience a profound increase in year-to-year variability in response to greenhouse forcing'* (Schar *et al.*, 2004). *'Hot extreme events are still expected to substantially increase in intensity, duration and frequency'* (Brown *et al.*, 2005). Despite its northerly location, the UK is not exempt to being affected by those trends, and a future heat wave crisis affecting the elderly is probable, and the effects could be as damaging as the 2003 French heat wave.

Similarly to the French heat wave plan that was set up in anticipation of future heat wave crises, a 'heat wave plan' has been also been set up in the UK, which sets out what needs to be done before and during a heat wave and what specific measures should be carried out to protect the groups of people who are most at risk. According to the NHS (Johnson *et al.*, 2004), older people, especially those above 75 years old and/or living on their own or in a care home, are particularly at risk during a heat wave.

2.4 Summary of the UK heat wave plan

A 'Heat-Health watch' system (Department of Health, 2004), which operates from the 1st of June to the 15th of September, and is based on the Met Office forecasts, alerts the Department of Health and other health-related institutions, which then release information to the public and health care professionals. Individuals most at risks are to be identified and be the first to receive advice on preventive measures. The media will be used as a means of transmitting information and advice to people quickly.

The 'Heat-Health watch' system comprises four levels of response and is based on threshold day and night time temperatures, defined by the Met Office, as detailed below:

Region	Threshold Temperature (°C)	
	Day	Night
London	32	18
South East	31	16
South West	30	15
Eastern	30	15
West Midlands	30	15
East Midlands	30	15
North West	30	15
Yorks & Humber	29	15
North East	28	15

Table 1: Threshold day and night temperatures defined by the Met Office by region (source: Department of Health, 2006)

As can be seen from the table above, the threshold temperatures vary according to the region in the UK, but the average is 30 °C during the day and 15 °C overnight. If temperatures go above the threshold temperatures given in the table, corresponding action is taken. Different levels of response have been set up in the plan, namely Awareness (level 1), Alert (level 2), Heat wave (level 3), and Emergency (level 4). Level 2 (Alert) is to be triggered if the Met Office forecasts threshold temperatures will be reached for at least three days ahead or in the case that there is an 80% or higher chance that the temperature will be high enough on at least two successive days to cause considerable impacts on health.

2.5 Relationship between temperature and mortality

2.5.1 Threshold and safe temperature limits

There exist no published safe temperature limits within which it can be considered that the risk of heat-related mortality is least, for care homes in the UK, but there is a set of summer comfort temperature guidelines for hospitals and health care buildings are given in CIBSE Guide A, Section 1.4. The summertime comfort limits are given as 23 to 25 °C for hospital wards. Also, according to the UK National Health Services (NHS), the internal temperature in hospitals should not exceed 25 °C and/or be 3 °C higher than the outside shade temperature. These guideline temperature limits however relate to comfort, whereas this report focuses mainly on the relation between heat and mortality.

Studies have however subsequently been carried to interpret the relation between heat and mortality, and the results have been used here as baseline data for estimating the safe temperature limits and threshold temperatures for care homes.

According to research carried out by Hajat *et al.* (2006) about the impact of hot temperatures on death in London, it was found out that heat-related deaths occur when the external air temperature goes above 19 °C and the relation between temperature and mortality beyond this value is linear, as shown in Figures 2, 3 and 4 below. Results also showed that heat-related deaths in London may begin at relatively low temperatures, as compared to other regions, and that heat episodes of long duration and of highest temperature had the largest effect on mortality, especially in the case of elderly people. In that study, hot days were defined as "those days when a three day moving average of temperature was above the percentile value seemed to adequately identify *periods* of sustained high temperatures rather than singling out individual days."

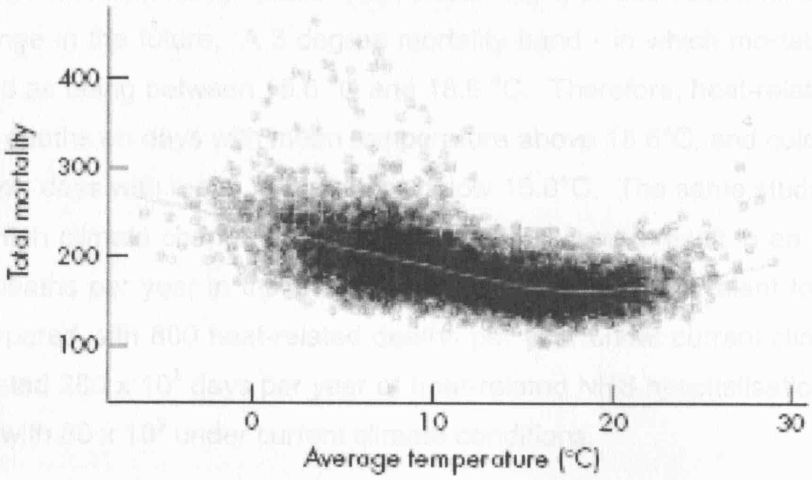
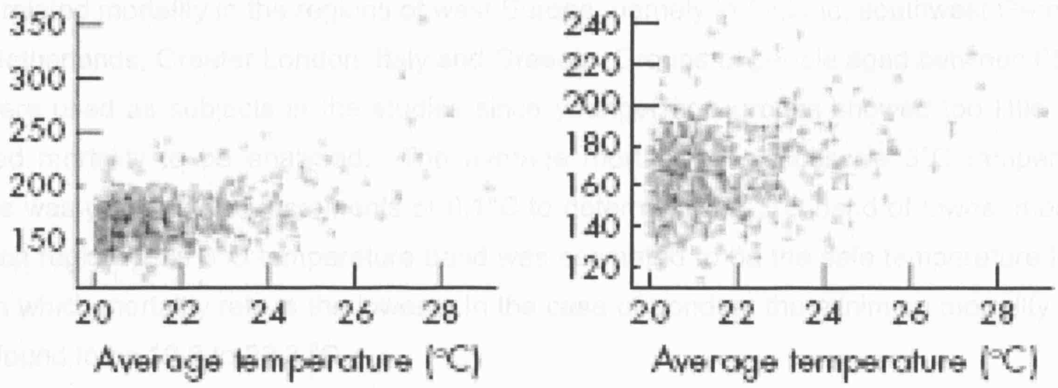


Figure 2: Plot of mortality against average temperature (source: Hajat et al., 2006)



Figures 3 and 4: Mortality-temperature relation for temperatures of 20°C and over, for all days (left) and for days during a heat wave in 1976 (right) (source: Hajat et al., 2006)

Average temperatures were used to determine the health effects of heat waves in this study, because it is the most realistic reflection of the amount of thermal exposure experienced throughout each whole day and night (Hajat *et al.*, 2006). Results also suggest that high night-time temperatures could have as much negative impact as high daytime temperatures in causing heat-related deaths, because it implies that there is no "cooling down" period. Also, minimum temperatures were found to have a larger effect on mortality as compared with maximum temperature, and the average temperature had a larger effect as compared to either maximum or minimum temperatures. Moreover, the largest increase in deaths occurred during periods of prolonged heat, suggesting that duration of exposure is an important issue to be considered as well.

A report produced by Donaldson *et al.* in 2001, at the request of the UK Department of Health, studied the impact of climate change on temperature-related mortality based on observed temperature-mortality relationship, assuming that this relationship is casual and does not change in the future. A 3 degree mortality band - in which mortality was lowest - was calculated as being between 15.6 °C and 18.6 °C. Therefore, heat-related deaths were defined as all deaths on days with mean temperature above 18.6°C, and cold-related deaths as all deaths on days with mean temperature below 15.6°C. The same studies showed that the Medium-High climate change scenario of the UKCIP would result in an estimated 2800 heat-related deaths per year in the UK in the 2050's, which is equivalent to an increase of 250% as compared with 800 heat-related deaths per year under current climate conditions; and an estimated 280 x 10^3 days per year of heat-related NHS hospitalisation in the 2050's, as compared with 80 x 10^3 under current climate conditions.

Subsequent studies were carried out by Keatinge *et al.* in 2006, which analysed age-specific heat-related mortality in the regions of west Europe, namely in Finland, southwest Germany, the Netherlands, Greater London, Italy and Greece. Groups of people aged between 65 and 74 were used as subjects in the studies since younger age groups showed too little heat-related mortality to be analysed. The average mortality at successive 3°C temperature bands was calculated at increments of 0.1°C to determine the 3°C band of lowest mortality in each region. This 3°C temperature band was estimated to be the safe temperature limits, within which mortality rate is the lowest. In the case of London, the minimum mortality band was found to be 19.3 to 22.3 °C.

The different studies carried out to reveal the trend between heat and mortality show slightly different results, but all the results tend to prove that temperatures beyond about 20 °C causes an increase in mortality, especially in the elderly. Considering the results from the various studies altogether, an appropriate threshold temperature and safe temperature limits within which heat-related deaths are minimum can be estimated. From the results of those studies, it can be assumed that the safe temperature limits are between 15 °C and 19 °C, and hence, that the threshold temperature after which heat-related mortality occurs is 19 °C. These limits however refer to the *external* temperature but the internal temperature in summer usually closely follows or is greater than outside temperature due to additional internal heat gains, unless appropriate cooling strategies are used to control it. Although there are no exact safe limits for internal temperature, it is clear that a certain internal temperature limit should be set to prevent heat-related deaths. According to the previous research results, as discussed above, the minimum safe external temperature limit is about 16 °C, the safe temperature limit ranging from about 16 to 22 °C. Considering the limitation proposed by the NHS in the case of hospitals, whereby the internal temperature should not be more than 3 °C higher than the external shade temperature, it can be assumed that the internal safe temperature limits would be between 19 and 25 °C, 25 °C being the threshold internal temperature in this case.

These temperature limits will then be used to assess overheating and the frequency of occurrence of heat-related deaths in the care homes in the UK, by running the TAS simulation models under the different future climate scenarios.

3. Climate change

3.1 Impacts of climate change

Climate change is one of the most serious issues of this century. The effects of climate change will influence both the natural environment and man-made environment, including the built environment. Some of the impacts of climate change on the built environment are that the energy use for heating and cooling will be affected, naturally ventilated buildings will overheat more frequently and the ability of low energy cooling systems to provide thermally comfortable conditions will also be altered. Buildings have long service lives and are usually designed with the aim that they would last at least several decades. It is therefore important to consider future climate change issues when designing buildings, otherwise the buildings created are likely to become obsolete within their useful lifetime, or will require costly and difficult modifications to the original building form at a later stage. As a result, it is essential that the effects of future climate change are addressed in a timely manner and that buildings are designed with the anticipated future climate in mind.

In 1998, the United Kingdom Climate Impacts Programme (UKCIP) released a set of climate change scenarios for the UK, in recognition of the need to make quantitative assessments of the possible impacts of climate change. The scenarios were then updated in 2002 and are now referred to as the 'UKCIP02' scenarios (Hulme *et al.*, 2002). The scenarios are being widely used to assess the possible impacts of climate change in the UK. At present, they represent the best available information on the likely course of climate change in the UK over the 21st century (Hacker *et al.*, 2005).

This chapter of the report examines existing climate data and the creation of projected climate data and weather files based on the past and current data available from CIBSE and UKCIP02. TAS-compatible weather files will then be created for future years, to assess the impact of climate change on care homes through the century ahead.

3.2 The UKCIP02 climate scenarios

Since it is impossible at present to have a perfect knowledge of the future and a perfect ability to model the future climate system, and to make a single confident prediction of the evolution of future climate, the UKCIP02 climate scenarios have been devised, based on a set of four 'storylines' for greenhouse gas emissions, taken from the Intergovernmental Panel on Climate Change (IPCC) SRES emissions scenarios. The scenarios illustrate the possible effects of choices being made around the world about technologies, lifestyles and values on the UK climate over the coming century, as these choices all affect to a certain extent the increase in greenhouse gas emissions and other pollutants.

Each of the scenarios is based on a different greenhouse gas emissions scenario, and do not take into account the global and national strategies to mitigate climate change; they merely assume different development paths for the world. The range of emissions scenarios chosen closely reflects the range of emissions published by the IPCC in their Third Assessment Report and have been categorised as *'Low Emissions'*, *'Medium-Low Emissions'*, *'Medium-High Emissions'* and *'High Emissions'*, as shown in Table 2 below.

Each of the storylines assumes a possible future scenario, from one that represents relatively high fossil fuel use and greenhouse gas emissions, to one that prioritises sustainability and which therefore makes less use of fossil fuels.

Table 2: The UKCIP emissions scenarios, based on Tables A.2 and A.3 of the UKCIP02 report (Source: Hulme et al., 2002)

UKCIP02 climate change scenario	IPCC SRES emissions storyline	UKCIP socio-economic scenario title	Description
Low Emissions	B1	Global Sustainability	Clean and efficient technologies; reduction in material use; global solutions to economic, social and environmental sustainability; improved equity; population peaks mid-century
Medium-Low Emissions	B2	Local Stewardship	Local solutions to sustainability; continuously increasing population
Medium-High Emissions	A2	National Enterprise	Self-reliance; preservation of local identities; continuously increasing population; economic growth on regional scales
High Emissions	A1F1	World Markets	Very rapid economic growth; population peaks midcentury; social, cultural and economic convergence among regions; market mechanisms dominate.

The global temperature change predictions under UKCIP02 were obtained by running the global climate model for the period from 1860 and 1990, and averaging the data for this thirty-year period to form the 'baseline' climate. The global climate model was then run until 2100 under each of the four emissions scenarios, and the data were averaged over three 30-year time-slices, namely the 2020s, 2050s and 2080s. The changes in global average air-temperature under each of the scenarios is shown in Figure 5 below.

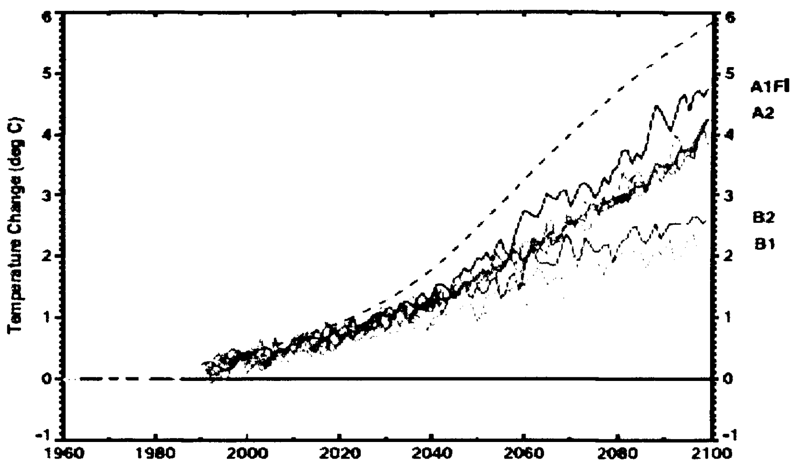


Figure 5: Annual global-average surface air temperature anomalies from 1961 to 2100 relative to the 1961-1990 average of 14 °C (Source: Hulme et al., 2002)

It can be seen from Figure 6 that, by 2100, the change in temperature with respect to the 1961-1990 average ranges from 2.1 °C for the B1 scenario to 4.8 °C for the A1FI scenario. The full range of global-average temperature changes by 2100 as reported by the Third Assessment Report of the IPCC, using all the SRES emissions scenarios and a number of global climate models from different modelling centres, lies between 1.5 °C and 5.9 °C.

The four emission scenarios along with the three time-slices would give a total of twelve climate variations to consider. However, the scenarios are mathematically linked and the differences between them are proportional, the proportionality being given by a 'climate scaling factor' (CSF) or 'pattern scaling factor), which is defined as the ratio of the global average temperature change in a scenario relative to that in the Medium-High 2080s scenario. The scenarios, time-slices and the corresponding scaling factors are given in Table 3 below:

Table 3: Global average temperature change according to UKCIP02 scenarios and the derived climate scaling factors (Source: Hulme et al., 2002)

Average global temperature change relative to 1960–1990	Climate scaling factor (CSF)	Emissions scenario	Time-slice
0.79	0.24	Low	2020s
0.88	0.27	Medium-Low	2020s
0.88	0.27	Medium-High	2020s
0.94	0.29	High	2020s
1.4	0.43	Low	2050s
1.6	0.50	Medium-Low	2050s

Average global temperature change relative to 1960–1990	Climate scaling factor (CSF)	Emissions scenario	Time-slice
1.9	0.57	Medium-High	2050s
2.0	0.61	Low	2080s
2.2	0.68	High	2050s
2.3	0.71	Medium-Low	2080s
3.3	1.0	Medium-High	2080s
3.9	1.18	High	2080s

The UKCIP02 climate scenarios contain monthly averaged values of climate variables recorded on the 50 km computational grid for the whole of UK. These variables are:

- temperature (daily average, maximum and minimum dry-bulb)
- total precipitation
- snowfall rate
- 10m wind speed
- relative and specific humidity
- total cloud in the longwave radiation band
- net surface long and shortwave radiation
- total downward shortwave radiation
- soil moisture content
- mean sea-level pressure
- surface latent heat flux.

3.3 Construction of the future weather data files

The thermal simulation of buildings provides an important tool in analysing the performance of both the building envelope and passive and active systems for heating and cooling. TAS building designer will be used in this case for thermal simulation of the care homes and to assess the impact of climate change on the buildings within this century. For the simulations to be carried out, external weather and climate data is required for the future years that will be considered. The required data is referred to as the design weather data, and is required to be hourly data for each of the years being considered.

The method which has been used here to produce future design weather data is a downscaling method termed 'morphing'. Present day design weather data are adjusted by the changes to climate forecast by global circulation models and regional climate models. This method has several advantages, which are outlined in Belcher *et al.* (2005) as the following:

- the 'baseline climate' is reliable, because it is the climate of the present-day weather series.
- the resulting weather sequence is likely to be meteorologically consistent.
- spatial downscaling is achieved because the present-day weather series is obtained from observations at a real location.

One drawback of this method is that the morphed design weather data for the future climate follows a similar trend and varies based on the present-day climate, but in reality, the future climate may have a different character. For instance, there is still research going on to determine whether the average temperature will increase through a constant warming over a certain period, or whether the frequency of heat waves will increase during the summer. However, "for the purpose of thermal simulation for real building design, the morphing method for producing design weather data under future climates is practical and gives future weather sequences that are both meteorologically self-consistent and a future climate that is consistent with the current best projections" (Belcher *et al.*, 2005).

The CIBSE/Met Office holds a set of hourly weather data for the years 1976–1995. The data available are for London, Manchester, and Edinburgh. There are two sets of years from CIBSE which are commonly used in assessing the performance of buildings. These are the Test Reference Year (TRY), which represents average weather conditions over the specified region and is commonly used for energy use predictions and the Design Summer Year (DSY), which is a weather year with a 'near-extreme' summer and is commonly used for overheating risk assessment and sizing of cooling systems.

The TRY consists of actual monthly weather sequences for each of the 12 calendar months, but the sequences come from different years and were selected so that the average dry bulb temperature was closest to the baseline climate mean dry bulb temperature for that particular month. Therefore, the TRY contains the average January climate data, followed by the average February climate data, and so on.

In the Design Summer Year (DSY), the mean dry bulb temperature from April to September has been selected to be as close to a near extreme summer for the baseline climate, and is defined as the middle upper quartile of the dry bulb temperature distribution from April to September. The DSY is intended principally for use in assessing overheating risk in naturally-ventilated buildings.

These sets of data may be considered as corresponding to the '1980s' time-slice, and has been used as the baseline data on which the changes have been applied to construct the future weather years.

The weather files have been created using Microsoft Excel, by applying the 'morphing' technique, as explained in the next sub-chapter, to combine the UKCIP02 predictions for changes to the mean climate with the CIBSE/Met Office weather years, so as to create TRY and DSY weather years for the time-slices 2020s, 2050s and 2080s. Hence, the 'morphed' future weather years have the mean properties of the monthly climate of the future UKCIP02 scenarios and the hourly weather variability of the CIBSE/Met Office weather years.

The assessment of overheating using projected weather data gives a valuable perception of the most likely impacts of climate change on the indoor environment, and in this case, a valuable insight into the risk of mortality within care homes when they are subject to overheating.

The number of possible combinations when considering the four UKCIP02 scenarios and three time-slices would add up to twelve. For the purpose of this project, the weather data used will be based on the present-day CIBSE DSY (1989) to assess the overheating criteria, and the future weather data will be projected from the latter under the UKCIP02 Medium-High climate change scenario for the three time-slices. This scenario is defined in UKCIP02 as follows: "The Medium-High scenario, which assumes preservation of local identities, continuously increasing population and economic growth on regional scales, is closest to the present world economy and pattern of energy use".

3.4 The morphing method

A set of algorithms have been used to morph the baseline CIBSE/Met Office climate files to create future weather files for the three time-slices under the Medium-High scenario. The climate data are morphed by taking into account the predictions from the regional climate model set up by the UKCIP02, which gives predictions of the changes to the monthly-mean values of the weather variables.

Since the climate change scenarios list changes to monthly-mean weather variables, the baseline climate must be calculated separately for each month. As explained by Belcher *et al.* (2005), "for each variable x_0, in the present day weather record, and for each month m in the calendar year, the baseline climatological value of x_0 for month m (denoted by $[x_0]_m$) is defined to be variable x_0 averaged over month m for all the averaging years", and can be represented symbolically as follows:

$$\langle x_0 \rangle_m = \frac{1}{24 \times d_m \times N} \sum_{N \ years} \sum_{month \ m} x_0$$

where N is the number of years in the averaging period and d_m is the number of days in month m and the 24 comes from averaging the hourly measurements over the 24 hours of each day. The monthly means calculated provide the baseline climate on which the morphing is based.

3.5 Variables in the CIBSE TRY and DSY climate data

The following are the set variables recorded in the CIBSE weather data:

Variable	Guide J: symbol (units)	Notes
Global solar irradiation on horizontal	gsr (W/h per m^2)	
Diffuse solar irradiation on horizontal	dsr (W/h per m^2)	
Sunshine duration: radiation site	sf_r (h)	
Sunshine duration: synoptic site	sf_s (h)	
Cloud cover	cc (oktas)	
Dry-bulb temperature	dbt (^{o}C)	
Wet-bulb temperature	wbt (^{o}C)	
Atmospheric pressure	atpr (mbar)	
Wind speed	ws (m/s)	Converted from speed logged in whole knots
Wind direction (degrees clockwise from true north, to nearest 108)	wd (degrees)	Degrees clockwise from true north, to nearest 10^{o}
Rain amount	ra (mm)	mm
Rain duration	rd (h)	
Present Weather Code	pwc	(0- 99) (see Guide J for details)
Solar altitude: degrees from horizontal	solalt (degrees from horizontal)	Computed from Yallop's algorithm, at HH - 30 min

Table 4: Weather variables recorded in the CIBSE weather data (source: Belcher et al., 2005)

3.6 Variables in the UCKCIP02 climate change scenarios

The UKCIP02 climate change projections are listed in terms of changes in a set of climate variables. The climate variables are as follows:

Variable	Symbol	Baseline climate 1961 - 1990 Units for variables	Climate-change scenarios 2020s, 2050s, 2080s Type of change and units:
Maximum temperature	TMAX	°C	absolute, °C
Minimum temperature	TMIN	°C	absolute, °C
Daily mean temperature	TEMP	°C	absolute, °C
Total precipitation rate	PREC	mm/month	percentage, %
Snowfall rate	SNOW	mm/month	percentage, %
10 m wind speed	WIND	m/s	percentage, %
Relative humidity	RHUM	%	absolute, %
Total cloud in longwave radiation	TCLW	%	absolute, %
Net surface longwave flux	NSLW	W/m^2	absolute, W/m^2
Net surface shortwave flux	NSSW	W/m^2	absolute, W/m^2
Total downward surface shortwave flux	DSWF	W/m^2	absolute, W/m^2
Soil moisture content	SMOI	mm	percentage, %
Mean sea level pressure	MSLP	hPa	absolute, hPa
Surface latent heat flux	SLHF	W/m^2	absolute, W/m^2
Specific humidity	SPHU	g/kg	percentage, %

Table 5: Variables in the UKCIP02 climate projections (source: Belcher et al., 2005)

The UKCIP02 variables listed above form part of the algorithms that have been used to create the projected climate data, and the changes to these variables, as predicted by the UKCIP02 scenarios, have been used in the calculation of the CIBSE variables for future years to finally create the future DSY and TRY weather files.

3.7 The morphing algorithms

The baseline climate, on which the morphing procedure will be applied, has to be calculated first. For it to be calculated, the monthly mean solar irradiance on the horizontal $\{gsr_0\}_m$, the mean monthly daily average temperature $\{T_0\}_m$, and the minimum and maximum temperatures $\{T_{0\ min}\}_m$ and $\{T_{0\ max}\}_m$, have to be calculated. The CIBSE DSY and TRY data is available as hourly values of the variables listed in Table 4 above. These data have been input into Excel and the mean solar irradiance, and the mean, minimum and maximum temperature required have been computed.

The next step is to apply the morphing procedure to each of the variables given in the CIBSE data, listed in Table 4. The variables which have been morphed are those that are required as input into the TAS weather utility to create the TAS-compatible weather files. These are: *dry bulb temperature, global radiation, diffuse radiation, cloud cover, humidity, wind speed* and *wind direction.*

For the above figures to be to be calculated, the CIBSE variables used were: *global solar irradiation on horizontal, diffuse solar irradiation on horizontal, cloud cover, dry-bulb temperature, wet-bulb temperature, atmospheric pressure, wind speed* and *wind direction.*

The 'scaling' factor' (e.g. αgsr_m representing the scaling factor for the global solar irradiation) is calculated for each variable to which the morphing procedure is to be applied.

The morphing algorithms, as defined by Belcher *et al.* (2005), and which have been applied to each of the variables, are described below:

1) Solar irradiance on horizontal, gsr ($Wm^{-2}h$)

In the UKCIP02 changes to climate variables, the solar shortwave flux is given as the total increase in monthly mean irradiation ($\Delta DSWF_m$), which corresponds to the solar irradiance on the horizontal in the weather files.

The scaling factor has been obtained using the following equation:

$$\boldsymbol{\alpha gsr_m = 1 + (\Delta DSWF_m / \{gsr_0\}_m)} \quad \text{........... (Equation 1)}$$

The scaling factor calculated above was then applied to all months, m, in the time series by multiplying it with the baseline hourly global solar radiation value, so as to obtain the projected gsr values for that specific time-series:

$$\boldsymbol{gsr = \alpha gsr_m \times gsr_0} \quad \text{........... (Equation 2)}$$

2) *Diffuse solar irradiance on horizontal, dsr ($Wm^{-2}h$)*

The change to diffuse irradiation is not provided by the UKCIP02 scenarios; therefore an indirect method has been used to calculate the projected *dsr* values. A simple model proposed by Belcher *et al.* (2005) assumes that dsr changes in proportion to *gsr*, so that projected values of dsr can be calculated using the following equation:

$$\mathbf{dsr = \alpha gsr_m \times dsr_0} \quad \text{............ (Equation 3)}$$

where αgsr_m has already been calculated using Equation 1 above.

3) *Cloud cover, oktas*

Cloud cover is generally recorded as the fraction of sky covered, and is represented on an integer scale of 0 to 8 in oktas, where 1 okta = 1/8th sky covered by cloud).

In UKCIP02, the proportion of cloud in the longwave radiation band, denoted by TCLW, and the increment is given as an absolute amount in percentage sky covered.

The first step is to convert the UKCIP02 increment from a percentage into oktas, using the following equation:

$$\mathbf{\Delta cc_m = INT(\Delta TCLW_m \times {}^{8}/_{100})} \quad \text{............ (Equation 4)}$$

To obtain the projected values of cloud cover for each time-series, the increment calculated using equation 4 is then added to each of the hourly values of cloud cover in the baseline data:

$$\mathbf{cc = cc_0 + \Delta cc_m} \quad \text{.............. (Equation 5)}$$

4) *Dry-bulb temperature, dbt (°C)*

The UKCIP02 scenarios gives changes to the daily mean temperature (TEMP), daily maximum temperature (TMAX), and daily minimum temperature (TMIN).

In this case, the required scaling factor is given by the equation:

$$\alpha dbt_m = \frac{\Delta TMAX_m - \Delta TMIN_m}{(dbt_{0\,\max})_m - (dbt_{0\,\min})_m} \quad \text{........... (Equation 6)}$$

The increment given by UKCIP02 is $\Delta TEMP_m$. The required equation to obtain the projected dry bulb temperature values is then:

$$\mathbf{dbt = dbt_0 + \Delta TEMP_m + \alpha dbt_m \times (dbt_0 - \{dbt_0\}_m)} \quad \text{........ (Equation 7)}$$

5) Relative humidity, %

There is no equation provided by Belcher or UKCIP02 to calculate projected values of relative humidity which is required for the creation of TAS weather files. RH has therefore been calculated using the equations given for calculating projections of wet-bulb and dry-bulb temperatures and calculating the relative humidity based on these data.

The Relative Humidity has been calculated using the following equations:

1. The conversion factor A, is calculated using the equation

   $\mathbf{A = 0.00066\ (1.0 + 0.00115\ T_{wb})}$ .... (Equation 8)

   where T_{wb} is the wet-bulb temperature.

2. The saturation vapour pressure at wet-bulb temperature (es_{wb}) is then calculated using the equation:

   $\mathbf{es_{wb} = e^{[(16.78\ Twb\ -\ 116.9)/(Twb\ +\ 237.3)]}}$ .... (Equation 9)

3. The vapour pressure, e_d is calculated using the equation:

   $\mathbf{e_d = es_{wb} - A\ P\ (T_{db} - T_{wb})}$ .... (Equation 10)

   where P is the atmospheric pressure

4. The saturation vapour pressure at dry-bulb temperature, es_{db} is next calculated using the equation:

   $\mathbf{es_{db} = e^{[(16.78\ T_{db}\ -\ 116.9)/(T_{db}\ +\ 237.3)]}}$ .... (Equation 11)

5. The relative humidity is finally calculated using the equation:

   $\mathbf{RH = E_d/Es_{db} \times 100\%}$ .... (Equation 12)

These equations have been applied to the hourly dry-bulb and wet-bulb data of each of the projected time-series so as to obtain projected data for relative humidity to be included in the TAS weather files.

6) Wind speed, ws (m/s)

The wind speed changes given in the UKCIP02 scenarios (WIND) are given as a percentage, whereas in the TAS climate files, it is required to be in m/s. Therefore, the projected wind speed for each time series is obtained by using the changes given in UKCIP02, and applying it as a stretch to the baseline wind speed, as shown below:

$$\mathbf{ws = (1 + WIND_m / 100) \times ws_0}$$

7) Wind direction, wd (degrees)

The wind direction is assumed to be the same as in the baseline climate data, since it is assumed that there is no change in the underlying weather. (Belcher *et al.*, 2005)

3.8 Changes to the climate variables

The UKCIP02 gives a set of changes to the climate variables, as explained in the previous section. These values are set up in a grid whose cells are relevant to different places around the UK. Since this report focuses on climate change and overheating in London, only the cells for London have been taken into account. These are set as four cells containing values for the predicted changes in the variables. These values have been averaged over the four computational grid cells so as to obtain the average predicted monthly changes to the climate variables. The cells used for London were cells 394, 395, 415 and 416.

It is interesting, in the context of this report, to look at the predicted increases in surface air temperature and other variables such as solar irradiance and relative humidity.

The projections of these variables have first been made using the morphing algorithms and the relevant changes from UKCIP02.

The changes in the climate variables were then computed based on the CIBSE DSY data, and are illustrated in the graphs below:

1. Changes in T_{max}

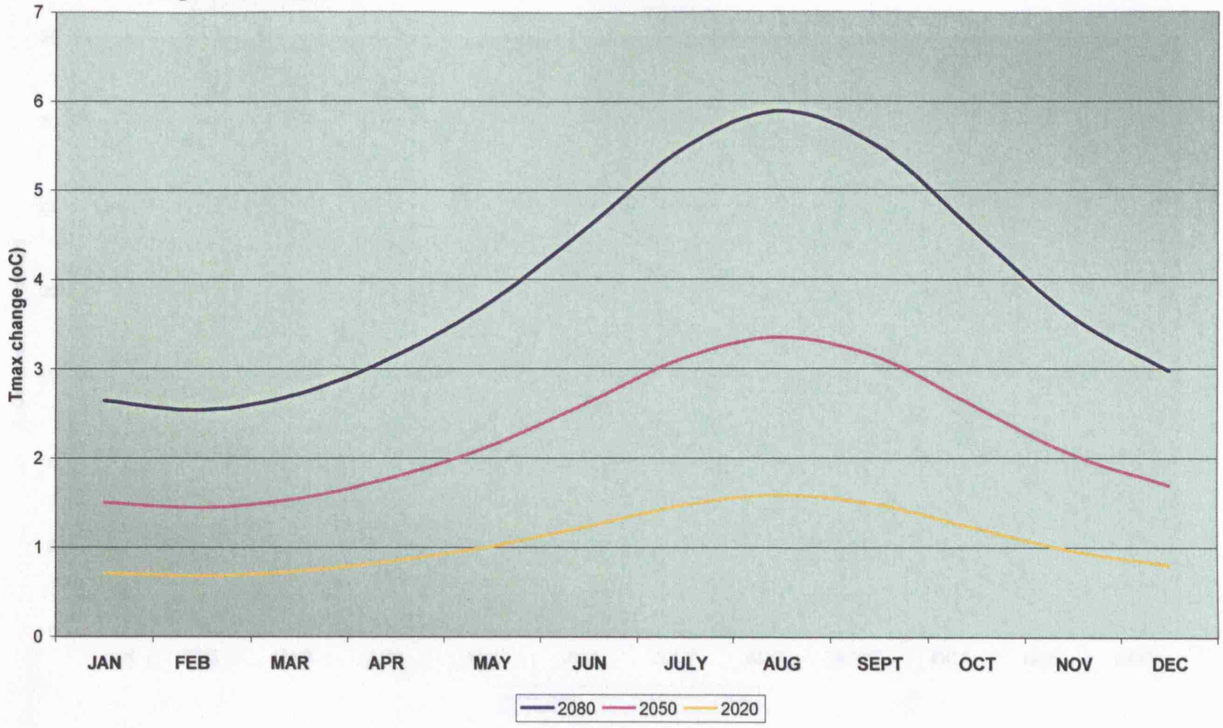


Figure 6: Predicted change in T_{max} for all time-series under the MH scenario

2. Changes in T_{min}

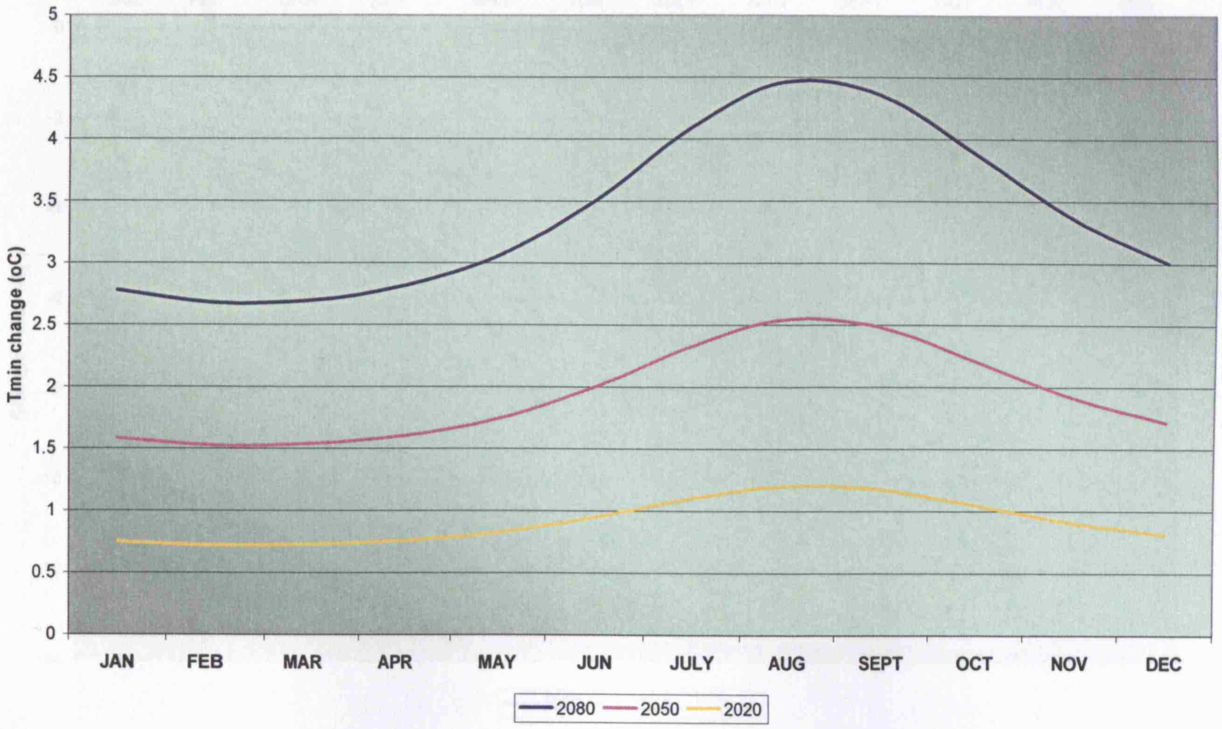


Figure 7: Predicted change in T_{min} for all time-series under the MH scenario

3. Changes in solar irradiance

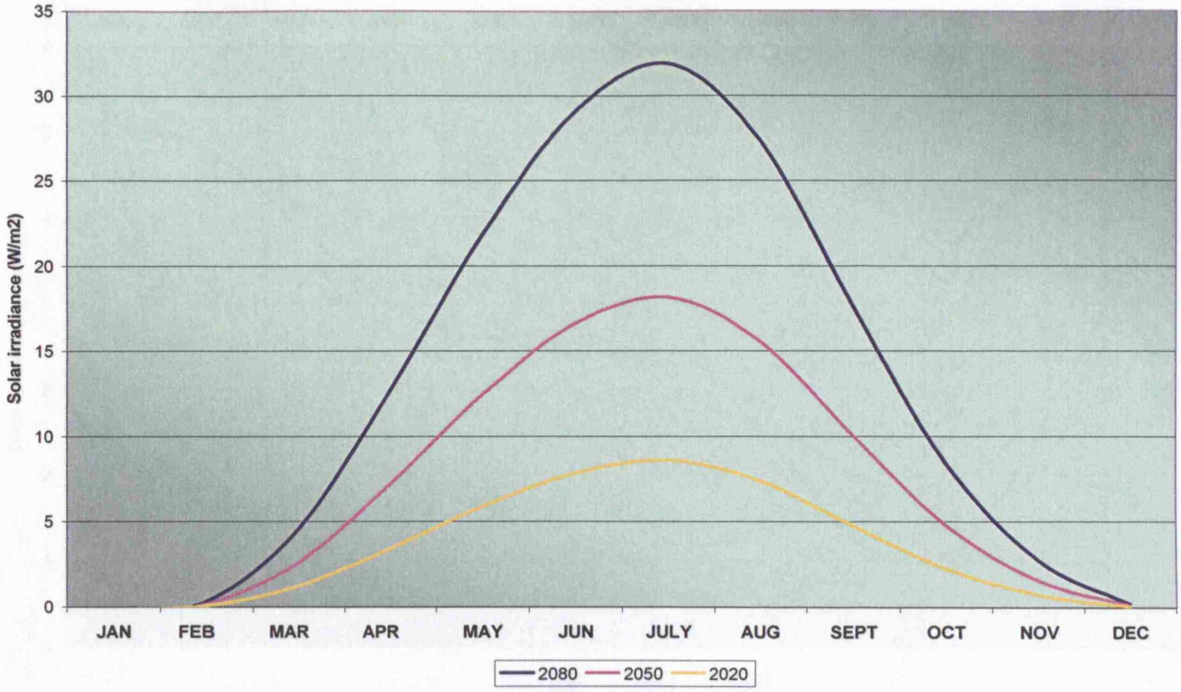


Figure 8: Predicted change in solar irradiation for all time-series under the MH scenario

4. Changes in relative humidity

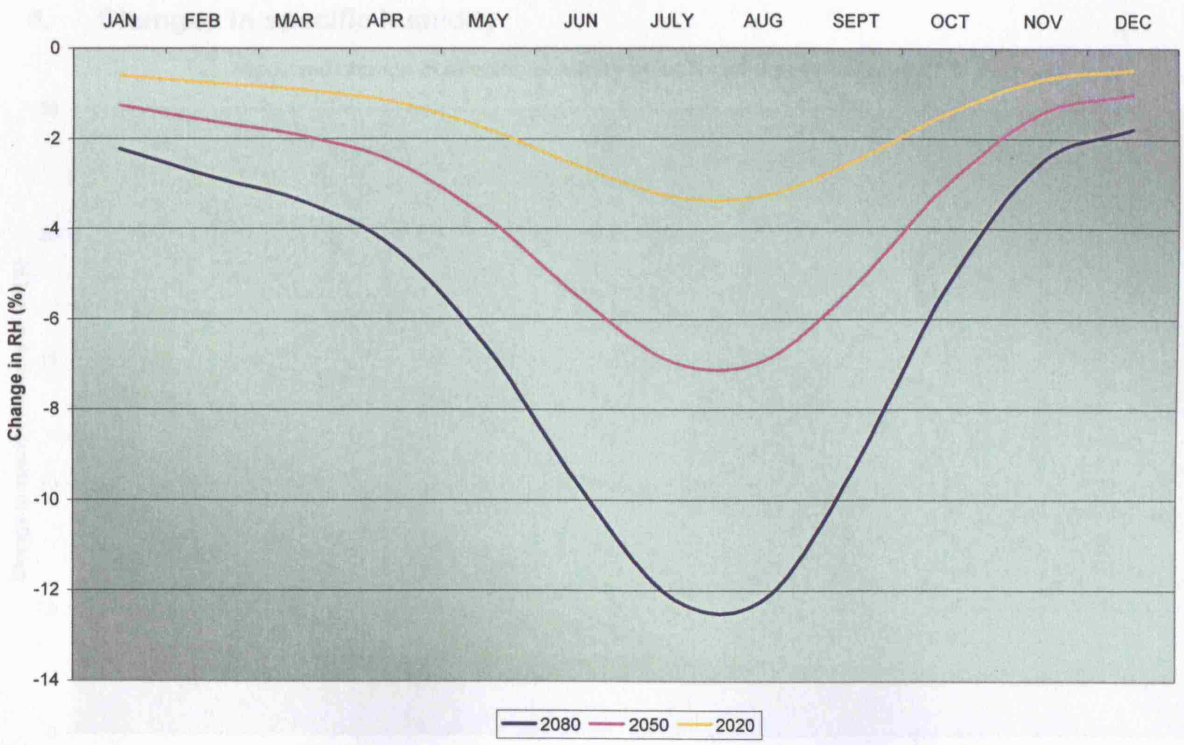


Figure 9: Predicted change in relative humidity for all time-series under the MH scenario

5. Changes in wind speed

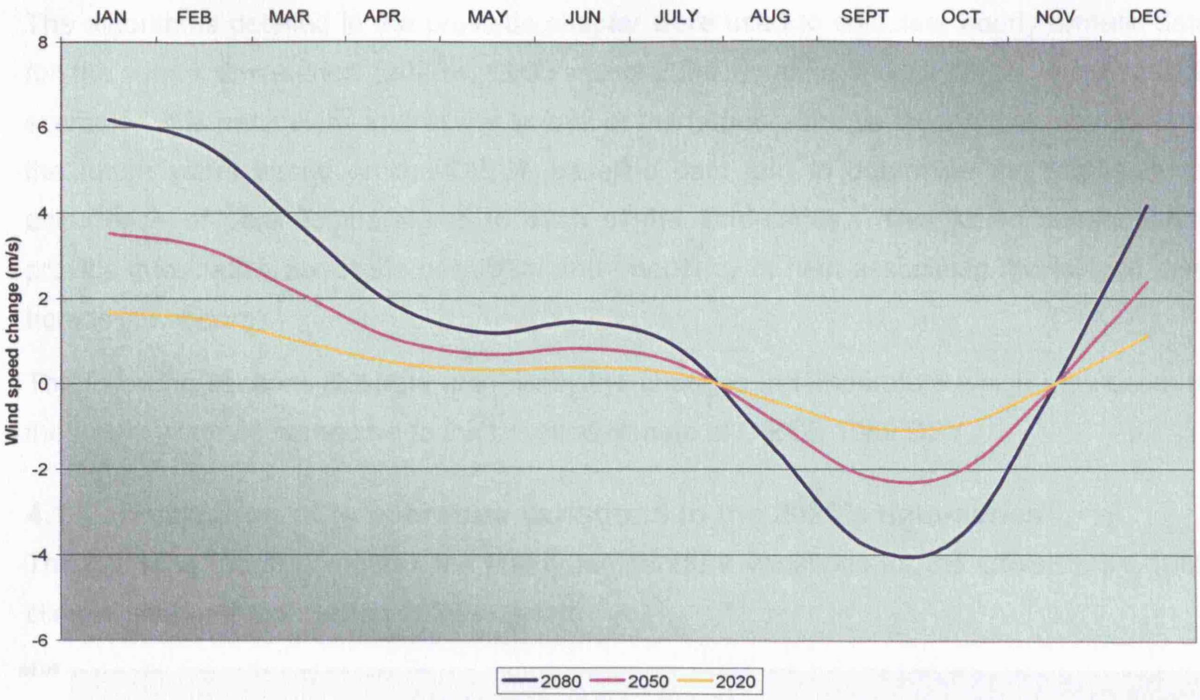


Figure 10: Predicted change in wind speed for all time-series under the MH scenario

6. Changes in specific humidity

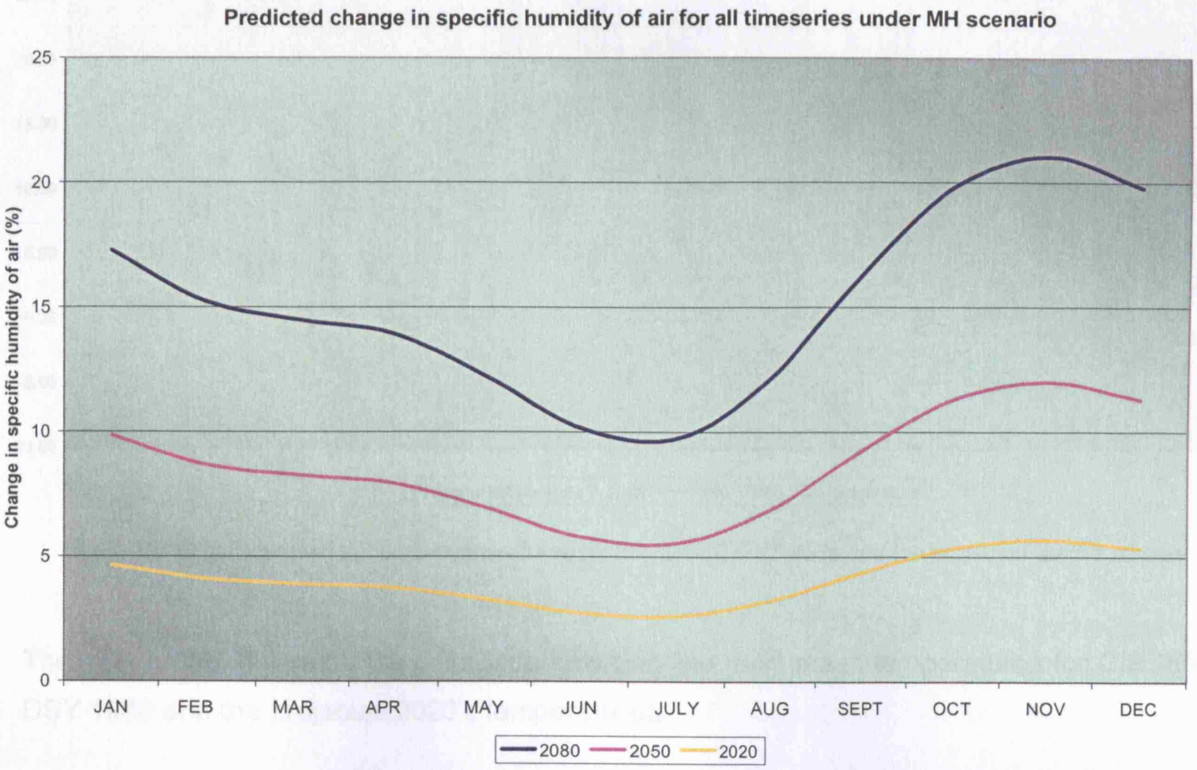


Figure 11: Predicted change in moisture content for all time-series under the MH scenario

4. Overview of the projected climate based on CIBSE DSY 1989

The algorithms detailed in the previous chapter were used to calculate hourly climatic data for the future time-series (2020's, 2050's and 2080's) under the UKCIP02 medium-high scenario. It is particularly interesting to look at the temperature variations that may occur in the future years based on the CIBSE baseline data and to determine the frequency of occurrence of peak temperatures in each of the time-series. This would subsequently provide information about the possibility and frequency of heat-associated mortality in care homes in London.

The following sections illustrate graphically the changes in temperature which may occur in the future years as compared to the baseline climate of CIBSE 1989 DSY.

4.1 Illustration of temperature variations in the 2020's time-series

The following graph compares the hourly temperature variations for the CIBSE DSY 1989 climate and for the projected 2020's climate.

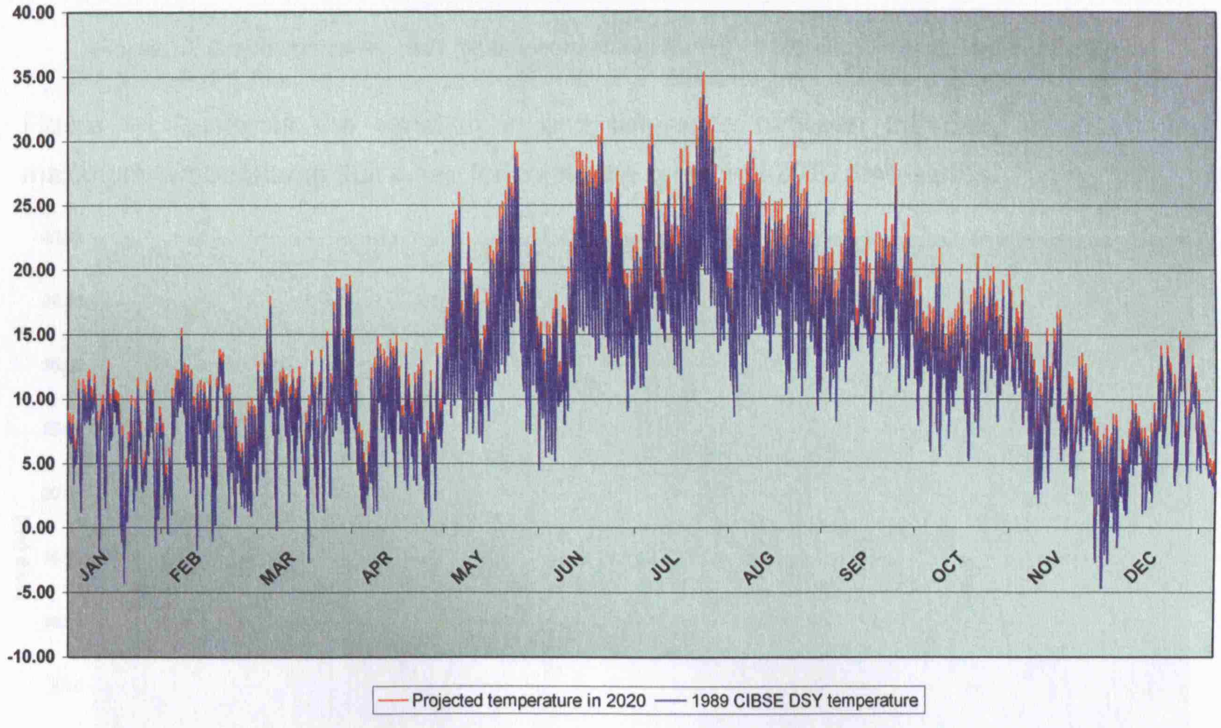


Figure 12: Graph comparing hourly temperatures for the CIBSE DSY 1989 and the projected 2020's climate

The next graph illustrates the difference between the daily mean temperatures for CIBSE's DSY 1989 and the projected 2020's temperatures.

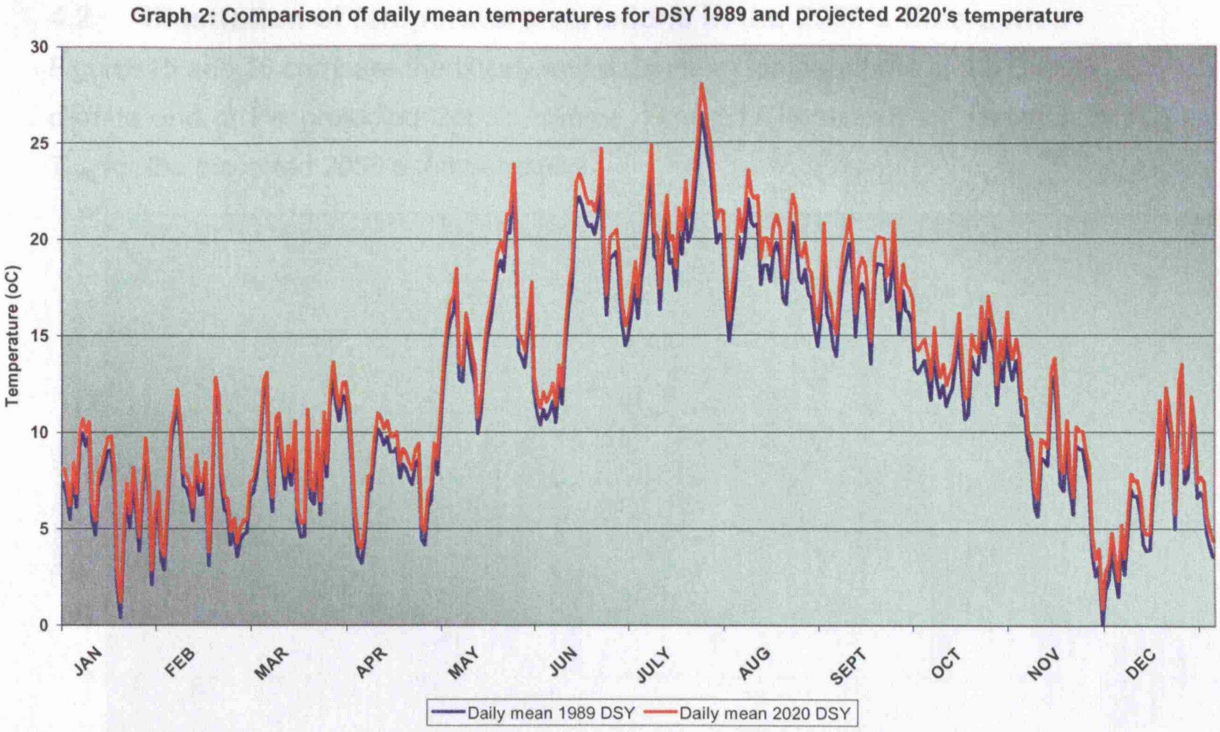


Figure 13: Graph comparing daily mean temperatures for DSY 1989 and the projected 2020's climate

Figure 14 illustrates the variation in and difference between the daily minimum and maximum temperatures that occur for during the projected 2020 time-series.

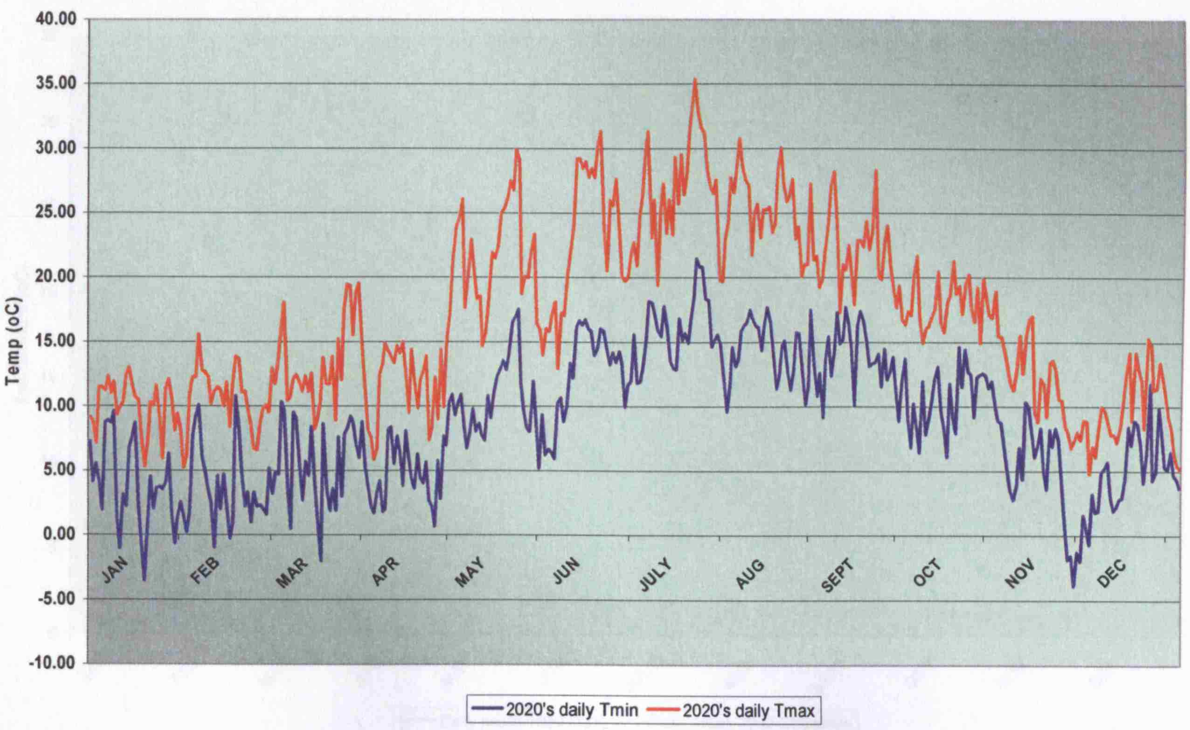


Figure 14: Graph showing variation of daily T_{max} and T_{min} during the projected 2020 time-series

4.2 Illustration of temperature variations in the 2050's time-series

Figures15 and 16 compare the hourly and daily mean temperatures of the CIBSE DSY 1989 climate and of the projected 2050's climate. Figure 17 illustrates the variation in T_{max} and T_{min} for the projected 2050's temperatures.

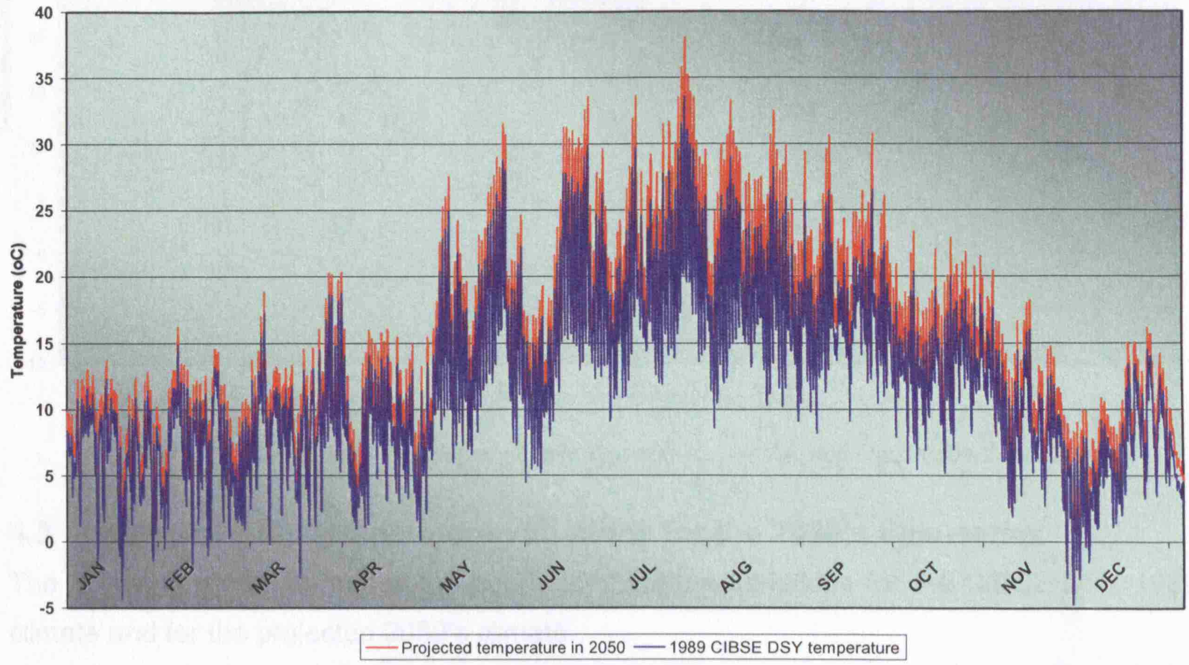


Figure 15: Graph comparing hourly temperatures for the CIBSE DSY 1989 and the projected 2050's temperatures

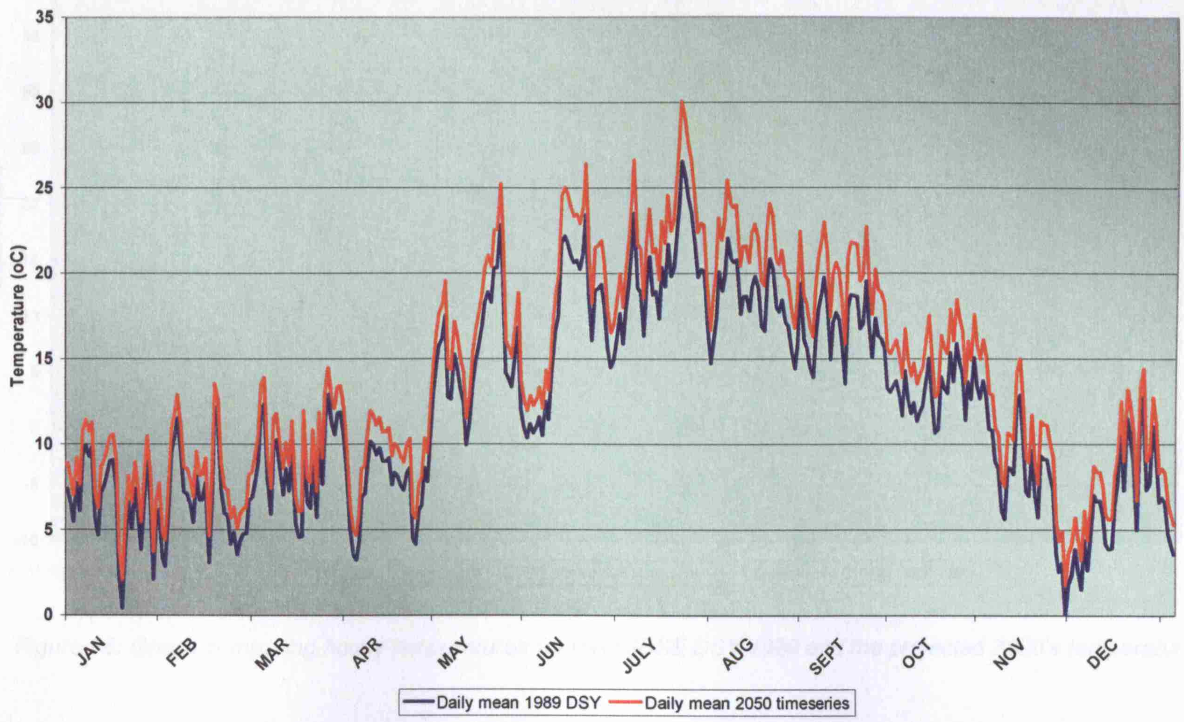


Figure 16: Graph comparing daily mean temperatures for DSY 1989 and the projected 2050's climate

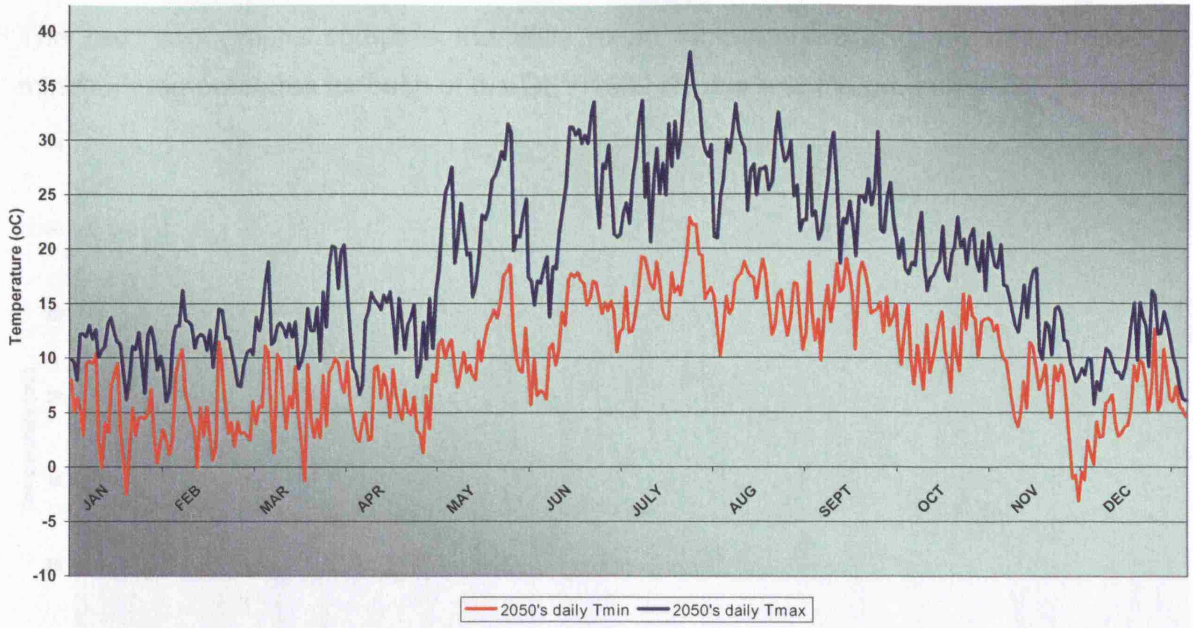


Figure 17: Graph showing variation of daily T_{max} and T_{min} for the projected 2050's time-series

4.3 Illustration of temperature variations for the 2080's time-series

The following graph compares the hourly temperature variations for the CIBSE DSY 1989 climate and for the projected 2080's climate.

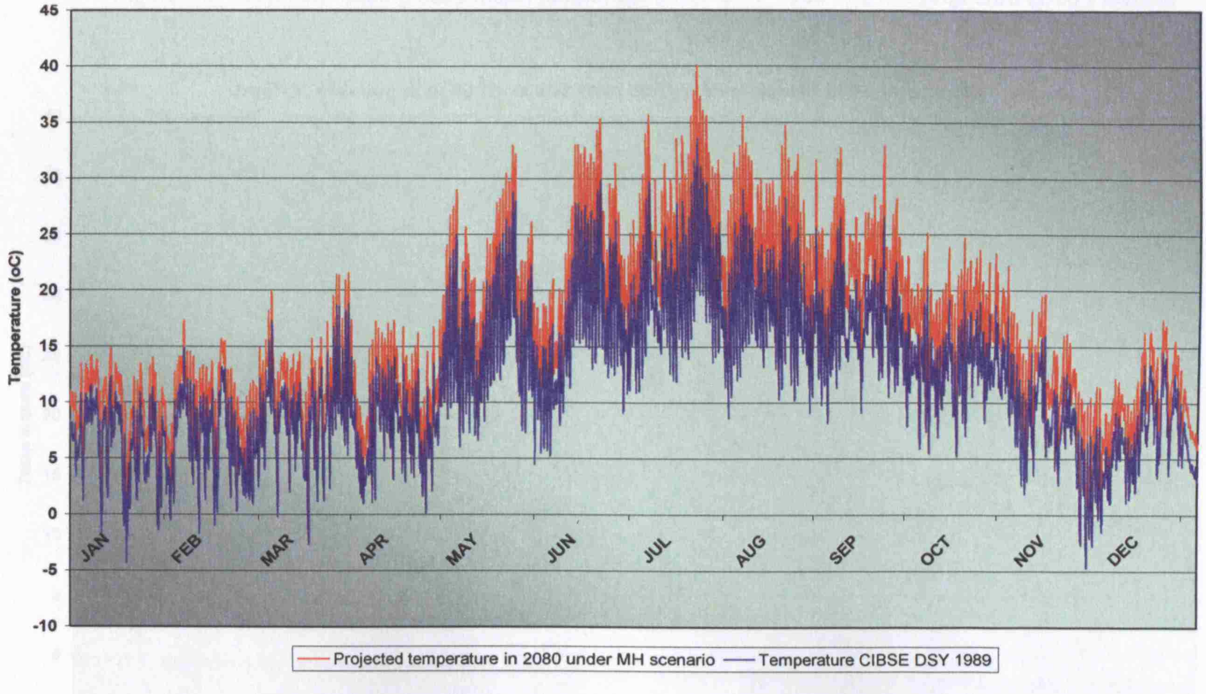


Figure 18: Graph comparing hourly temperatures for the CIBSE DSY 1989 and the projected 2080's temperatures

The next two graphs compare the daily mean temperatures and the daily maximum and minimum temperatures for each of the DSY 1989 climate and the projected 2080's climate.

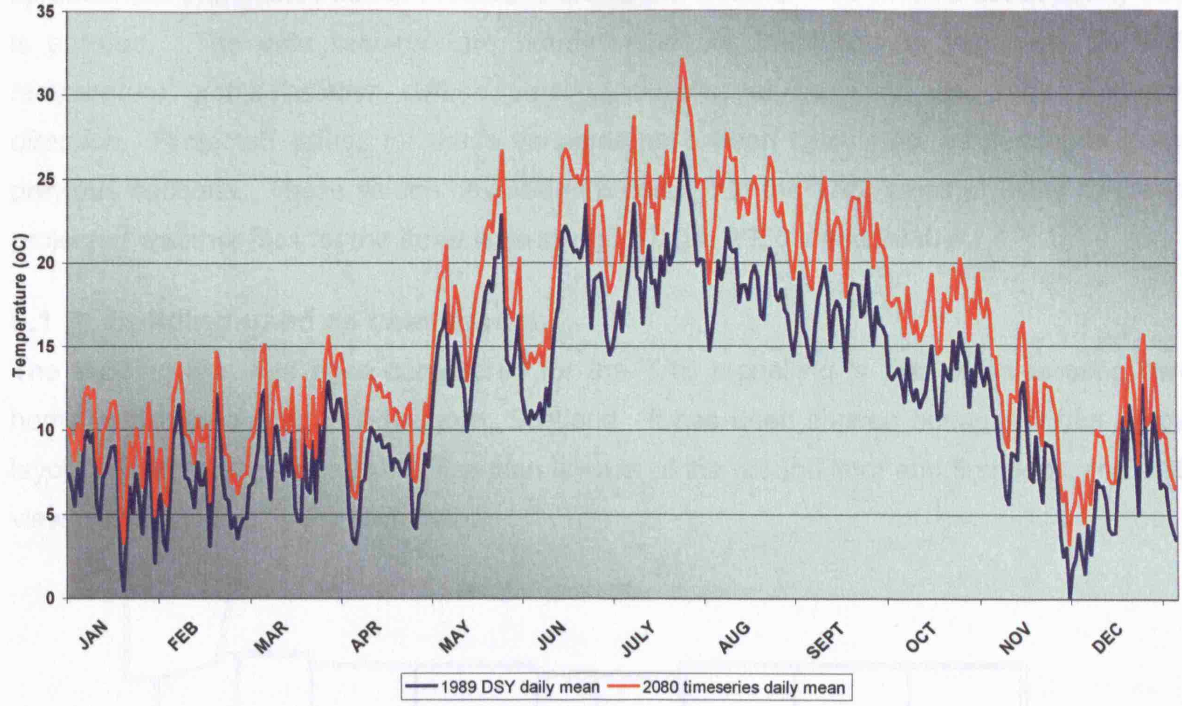


Figure 19: Graph comparing daily mean temperatures for DSY 1989 and the projected 2080's climate

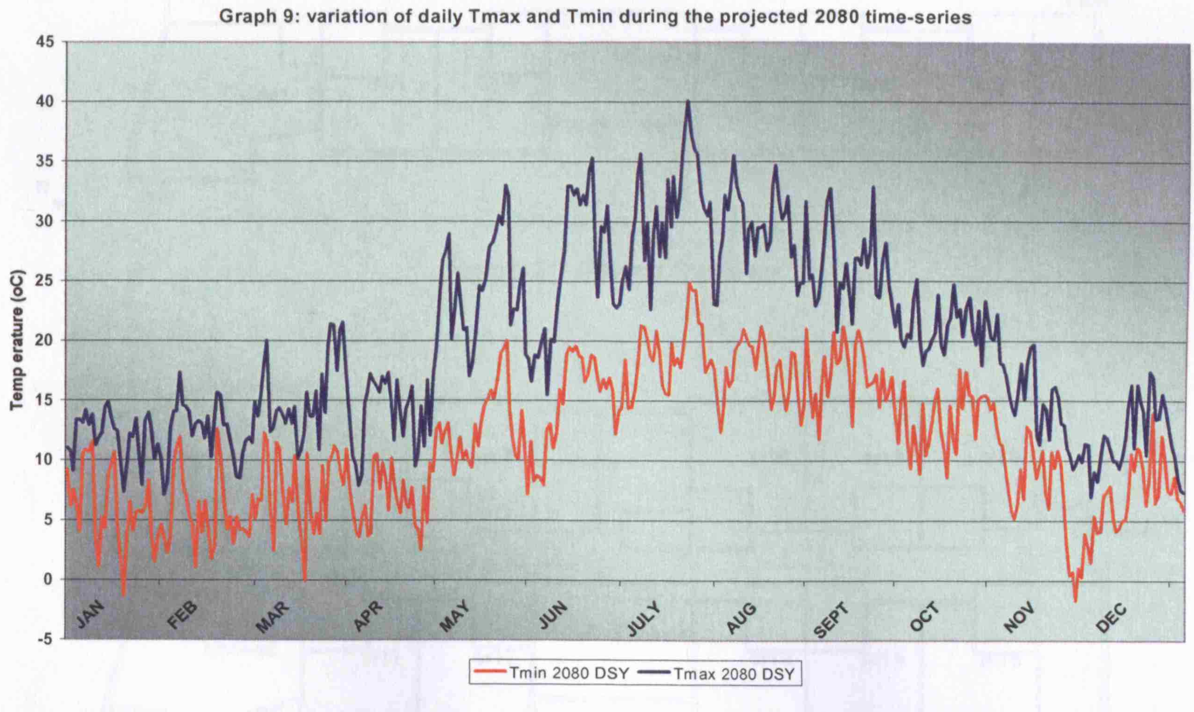


Figure 20: Graph showing variation of daily T_{max} and T_{min} for the projected 2080's time-series

5. TAS modelling

TAS-compatible weather files were created using the TAS weather utility, an Excel spreadsheet that makes use of macros to create the weather files when a set of hourly data is entered. The data required are hourly values of the following variables: *dry bulb temperature, global radiation, diffuse radiation, cloud cover, humidity, wind speed* and *wind direction*. Projected values for these variables have been calculated, as described in the previous sections. These values have been entered into the TAS 'weather utility' to create projected weather files for the three time-slices: 2020's, 2050's and 2080's.

5.1 Building used as case model

The building that has been considered for the TAS modelling is that of an existing care home, which is located in Edinburgh, Scotland. It has been chosen because it has typical layout of care homes in the UK. The plan layouts of the ground floor and first floor, and a 3D view of the building, are shown below:

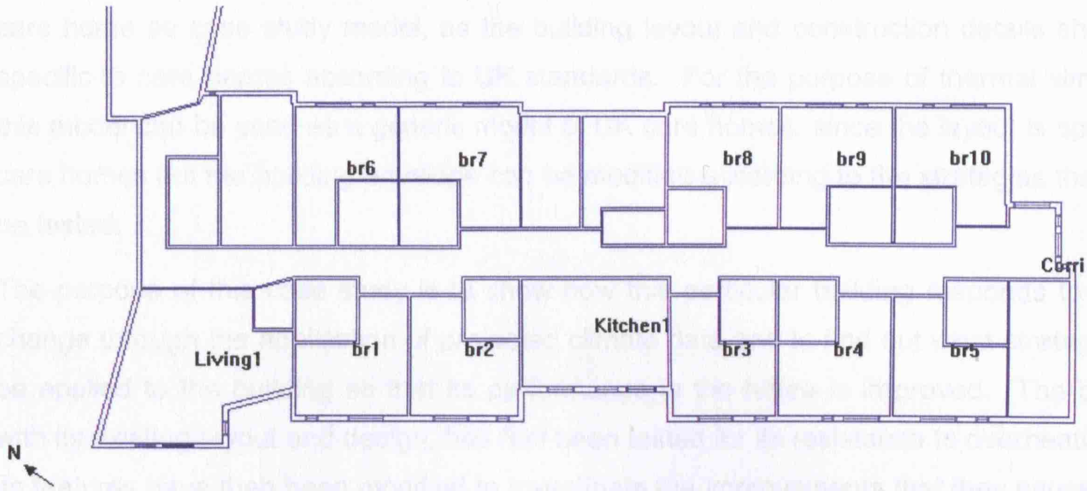


Figure 21: Ground floor plan

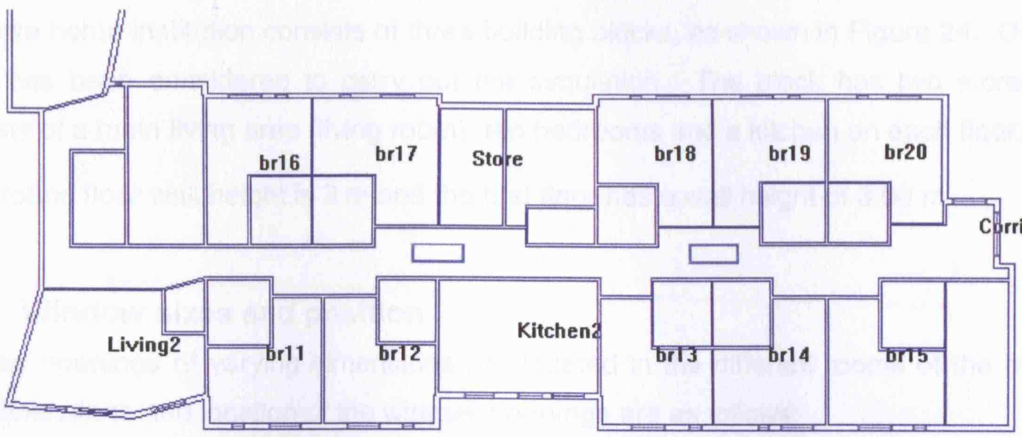


Figure 22: First floor plan

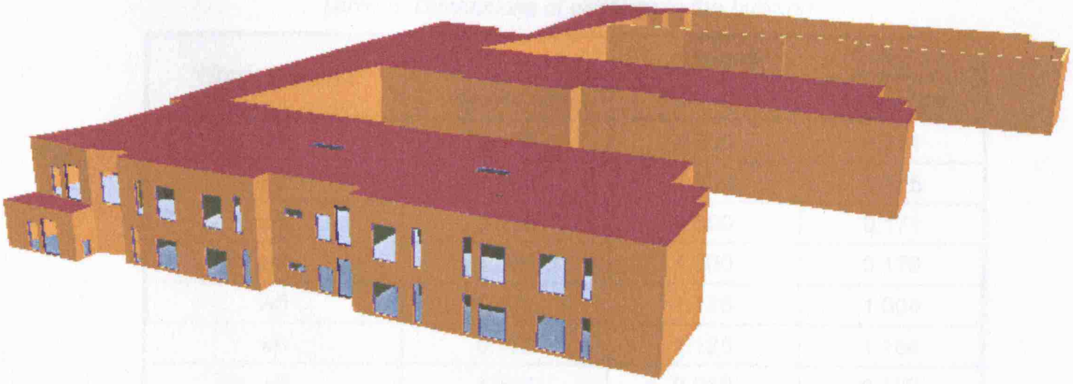


Figure 23: 3D view of the care home in TAS

The building has been selected as case study as it is a good representation of the particular layout of care homes in the UK. It also stands as a good example of how application of different passive strategies can improve internal conditions in the summer, since the building structure is designed in such a way as to be efficient in both summer and winter (good insulation, thermal mass, rooflights, etc.). In addition, it was important to use an existing care home as case study model, as the building layout and construction details should be specific to care homes according to UK standards. For the purpose of thermal simulation, this model can be used as a generic model of UK care homes, since the layout is specific to care homes but the building envelope can be modified according to the strategies that are to be tested.

The purpose of this case study is to show how this particular building responds to climate change through the application of projected climate data and to find out what strategies can be applied to the building so that its performance in the future is improved. The building, with its existing layout and design, has first been tested for its resistance to overheating, and its features have then been modified to investigate the improvements that they cause on the internal environment.

The care home institution consists of three building blocks, as shown in Figure 24. Only one block has been considered to carry out the simulation. The block has two storeys and consists of a main living area (living room), ten bedrooms and a kitchen on each floor.

The ground floor wall height is 3 m and the first floor has a wall height of 3.50 m.

5.1.1 Window sizes and position

Window openings of varying dimensions are located in the different rooms of the building. The dimensions and location of the window openings are as follows:

Table 6: Dimensions of windows in the building

Window name	Dimensions		
	Height (m)	Width (m)	Level (m)
w1	2.138	0.500	0.171
w2	1.790	1.500	0.175
w3	2.138	0.500	0.171
w4	1.969	1.360	0.176
w5	0.472	1.125	1.004
w6	0.472	1.125	1.164
w7	1.517	0.950	0.102
w8	1.517	0.950	0.102
w10	2.440	0.850	1.000
w12	2.037	1.000	0.120
w13	2.138	0.500	0.101
w14	2.138	0.500	0.101
w15	0.975	0.260	1.153
w16	0.975	0.260	1.173
w17	0.650	0.910	1.000
w18	1.100	0.810	1.000
w20	1.802	0.800	0.099
w21	0.950	0.554	0.095
rl1 (rooflight)	2.000	0.750	-

The next table details the location of each of the windows listed in Table 6 above.

Table 7: Location of windows openings

Ground Floor		First Floor	
Room	Window name	Room	Window name
Living room	w20, w21	Living room	w4, w20
Kitchen	w5, w7	Kitchen	w6, w8
Bedroom 1	w1, w2	Bedroom 11	w3, w4
Bedroom 2	w1, w2	Bedroom 12	w3, w4
Bedroom 3	w1, w2	Bedroom 13	w3, w4
Bedroom 4	w1, w2	Bedroom 14	w3, w4
Bedroom 5	w1, w2	Bedroom 15	w3, w4
Bedroom 6	w1, w2	Bedroom 16	w3, w4
Bedroom 7	w1, w2	Bedroom 17	w3, w4
Bedroom 8	w1, w2	Bedroom 18	w3, w4
Bedroom 9	w1, w2	Bedroom 19	w3, w4
Bedroom 10	w1, w2	Bedroom 20	w3, w4
Corridor	w11, w13, w2, w15	Corridor	w4, w12, w14, w16
		Roof	rl1

5.1.2 Construction details

Ground floor

The ground floor in the existing building consists of a first layer of crushed brick aggregate, followed by a layer of concrete with 3% moisture content, topped by concrete screed and plastic flooring.

Opaque Construction | Name: ground\1 | Description: Ground floor no false floor

Solar Absorptance		Emissivity		Conductance (W/m2 C)	Time Constant (hours)
ext. surf.	int. surf.	External	Internal		
0.760	0.500	0.910	0.900	0.297	127.999

Layer	M-Code	Width (...	Conduc...	Convec...	Vapour ...	Density	Specific...	Description
Inside	am1tile\8	5.0	0.500	0.000	99.000	1050.000	837.000	PLASTIC *3
2	am1concd\9	50.0	1.280	0.000	34.000	2100.000	1000.000	CONCRETE SCREE...
3	am1concd\1	125.0	0.870	0.000	14.800	1800.000	920.000	CONCRETE 3% m.c....
4	am1aggr\4	75.0	0.550	0.000	12.000	1580.000	1057.000	CRUSHED BRICK A...
5	am1soil\7	1000.0	0.329	0.000	99.000	1515.000	796.000	SAND, DRY *2

Ceiling

The ground floor ceiling/first-floor flooring consists of acoustic tiles, followed by a 200 mm air gap, a layer of 3% m.c. concrete, concrete screed and carpet finish.

Opaque Construction | Name: ceiling\1 | Description: Ceiling with ceiling void no false flr

Solar Absorptance		Emissivity		Conductance (W/m2 C)	Time Constant (hours)
ext. surf.	int. surf.	External	Internal		
0.700	0.500	0.900	0.900	1.222	13.949

Layer	M-Code	Width (...	Conduc...	Convec...	Vapour ...	Density	Specific...	Description
Inside	am1tile\1	15.0	0.058	0.000	14.000	288.000	586.000	ACOUSTIC TILE/PA...
2	am1cav\16	200.0	0.000	1.300	1.000	0.000	0.000	200MM AIR (UPWA...
3	am1concd\1	150.0	0.870	0.000	14.800	1800.000	920.000	CONCRETE 3% m.c....
4	am1concd\9	50.0	1.280	0.000	34.000	2100.000	1000.000	CONCRETE SCREE...
5	am1fin\3	10.0	0.060	0.000	2.000	186.000	1360.000	CARPET *2

Roof

The roof is made up of roofing felt on the outside, below which there is mineral wool acting as insulation, followed by a 100 mm air gap and plasterboard on the inside.

Opaque Construction | Name: roof\4 | Description: Flat roof U 0.16

Solar Absorptance		Emissivity		Conductance (W/m2 C)	Time Constant (hours)
ext. surf.	int. surf.	External	Internal		
0.740	0.400	0.910	0.900	0.125	8.879

Layer	M-Code	Width (...	Conduc...	Convec...	Vapour ...	Density	Specific...	Description
Inside	am1plast\20	20.0	0.160	0.000	11.000	960.000	837.000	PLASTERBOARD *4
2	am1cav\15	100.0	0.000	1.300	1.000	0.000	0.000	100MM AIR (UPWA...
3	am1ins\6	300.0	0.039	0.000	1.150	150.000	840.000	MINERAL WOOL, FI...
4	am1asph\9	5.0	0.410	0.000	1300.000	960.000	1000.000	ROOFING FELT 1 *2

External walls

The external walls consist of lightweight plasterboard on the inside, followed by a 10 mm air gap, aerated autoclaved concrete blocks, glass fibre insulation, and cement rendering on the outside.

Opaque Construction | Name: wallext\4 | Description: Brick and block external wall U=0.25

Solar Absorptance		Emissivity		Conductance (W/m2 C)	Time Constant (hours)
ext. surf.	int. surf.	External	Internal		
0.400	0.400	0.900	0.900	0.250	13.244

Layer	M-Code	Width (...	Conduc...	Convec...	Vapour ...	Density	Specific...	Description
Inside	am1plast\1	10.0	0.079	0.000	11.000	400.000	837.000	LIGHTWEIGHT PLA...
2	am1cav\1	10.0	0.000	2.500	1.000	0.000	0.000	10MM AIR (HORIZO...
3	am1block\15	140.0	0.250	0.000	6.800	800.000	1063.000	AERATED, AUTOC...
4	am1ins\2	110.0	0.035	0.000	2.880	25.000	1000.000	GLASS FIBRE 2 *3
5	am1plast\23	10.0	0.500	0.000	19.200	1300.000	769.000	CEMENT RENDERI...

Internal walls

Internal walls are made up of 25 mm wide lightweight plasterboards, sandwiching foamed slag concrete blocks 100 mm wide.

Opaque Construction | Name: wallint\1 | Description: plastered block internal wall

Solar Absorptance		Emissivity		Conductance (W/m2 C)	Time Constant (hours)
ext. surf.	int. surf.	External	Internal		
0.400	0.400	0.900	0.900	1.054	5.832

Layer	M-Code	Width (...	Conduc...	Convec...	Vapour ...	Density	Specific...	Description
Inside	am1plast\1	25.0	0.079	0.000	11.000	400.000	837.000	LIGHTWEIGHT PLA...
2	am1block\1	100.0	0.317	0.000	14.800	1040.000	1050.000	FOAMED SLAG CO...
3	am1plast\1	25.0	0.079	0.000	11.000	400.000	837.000	LIGHTWEIGHT PLA...

Glass panes

The two types of glass panes used in the building are sunhp/2 and sunhp/15 panes already listed in the transparent constructions folder.

Transparent Construction | Name: sunhp\2 | Description: 6mm sunHP 52/42 neutral,12mm,6mm optiflo

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m2 C)	Time Constant (hours)	External Blind	Internal Blind
	ext. surf.	int. surf.	int. surf.	ext. surf.		External	Internal				
0.340	0.399	0.068	0.172	0.307	0.797	0.873	0.845	2.390	0.000	NO	NO

Layer	M-Code	Widt...	Solar...	Ext S...	Int S...	Ext E...	Int E...	Cond...	Conv...	Vapo...	Description
Inside	optclear\2	6.0	0.780	0.070	0.070	0.845	0.845	1.000	0.000	9999...	6mm Optifloat c...
2	am1cav\2	12.0	0.000	0.000	0.000	0.000	0.000	0.000	2.080	1.000	12MM AIR (HO...
3	sunhp\3	6.0	0.430	0.180	0.180	0.873	0.075	1.000	0.000	9999...	6mm suncool H...

Transparent Construction | Name: sunhp\15 | Description: Sunhp/2 with internal blind light

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m2 C)	Time Constant (hours)	External Blind	Internal Blind
	ext. surf.	int. surf.	int. surf.	ext. surf.		External	Internal				
0.026	0.469	0.262	0.547	0.027	0.059	0.873	0.845	1.750	0.000	NO	YES

Layer	M-Code	Widt...	Solar...	Ext S...	Int S...	Ext E...	Int E...	Cond...	Conv...	Vapo...	Description
Inside	am1blind\2	1.0	0.070	0.400	0.400	0.845	0.845	999....	0.000	9999...	MEDIUM BLIND
2	am1cav\2	12.0	0.000	0.000	0.000	0.000	0.000	0.000	2.080	1.000	12MM AIR (HO...
3	optclear\2	6.0	0.780	0.070	0.070	0.845	0.845	1.000	0.000	9999...	6mm Optifloat c...
4	am1cav\2	12.0	0.000	0.000	0.000	0.000	0.000	0.000	2.080	1.000	12MM AIR (HO...
5	sunhp\3	6.0	0.430	0.180	0.180	0.873	0.075	1.000	0.000	9999...	6mm suncool H...

5.1.3 Internal conditions

The internal conditions prevailing in the original building are as follows:

Table 8: Summary of internal conditions prevailing in the building

Internal Gains	Zones			
	Corridor	Kitchen	Bedroom	Living room
Infiltration	0.5 ach, 24h	0.4 ach, 24h	0.35 ach, 24h	0.4 ach, 24h
Ventilation	0	0	0.5 ach, 24 h	0
Lighting gain	0	0	0.40 W/m², Care bedroom lighting	2 W/m², Living room occupancy
Occupancy sensible gain	0	6 W/m², Kitchen occupancy	5 W/m², Care bedroom occupation	20 W/m², Living room occupancy
Occupancy latent gain	0	5 W/m², Kitchen occupancy	3 W/m², Care bedroom occupation	15 W/m², Living room occupation
Equipment sensible gain	0	7 W/m², Kitchen occupancy	5 W/m², Care bedroom occupation	3 W/m²
Equipment latent gain	0	10 W/m², Kitchen occupancy	0	0
Heating emitter	0	0	0	0
Cooling emitter	0	0	0	0
Thermostat	0	0	0	0

Time schedules have been applied in order to control the opening of windows and the control of lighting, equipment and occupation gains in the building. The schedules that have been set up are as follows:

Time schedule	
Living room occupation	8 am - 4 pm
Care bedroom lighting	5 pm – 11 am
Care bedroom occupation	8 pm – 7 am
Kitchen occupation	8 am – 5 pm

5.1.4 Opening schedules

The window opening schedule (zdwon) that have been used in the original building is set so that the windows start opening at 21 °C, are fully open at 23 °C, and close when the wind speed goes above 5 m/s.

This opening schedule was been applied to windows *w1, w2, w3* and *w4*.

5.2 Resulting internal temperatures

The original building was first tested for overheating in the case model by applying the 1989 CIBSE DSY weather file using TAS building designer.

For this initial case study, the layout, building envelope and construction materials of the original building have been unchanged and projected weather files applied to that existing building form so as to assess the level of overheating.

Whole year performance summary

	Value	Unit	Zone	Day	Hour
Max Air Temp	40.49	C	2	202	16
Min Air Temp	19.46	C	25	156	5
Max Humidity	100.00	%	23	157	16
Min Humidity	22.08	%	2	155	19
Max Heating Load	0.00	kW	0	0	0
Max Cooling Load	0.00	kW	0	0	0
Max Latent Addition	0.00	kW	0	0	0
Max Latent Removal	0.07	kW	23	188	14
Max Resultant Temp	39.81	C	2	202	16
Min Resultant Temp	19.96	C	25	156	5
Max MRT	39.13	C	2	202	16
Min MRT	20.40	C	25	160	4
Max External Temp	33.60	C	0	203	16
Min External Temp	5.20	C	0	156	3
Max External Humidity	100.00	%	0	162	5
Min External Humidity	26.52	%	0	202	16

5.3 Internal temperatures during days with peak summer temperatures

The following graphs show the resulting internal temperatures during peak summer days in the living room, bedroom and kitchen.

Hottest summer day (days 202 and 203)

From the CIBSE DSY 1989 weather file, the highest external temperature occurred on the 22nd of July (day 203), the temperature reaching a peak of 33.6 °C on that specific day. According to the TAS simulation results, the highest temperature (40.49 °C) inside the building occurred on the 21st of July (day 202) in the living room. This is a significantly elevated temperature, falling far off the safe temperature limits. It can also be seen from Figures 25 and 26 that the temperature constantly remained above 30 °C during the whole day in the living room, therefore residents could very probably suffer from heatstroke unless air-conditioning is used.

The following graphs illustrate the temperatures in the living room, bedroom and kitchen on the 21st July, when the internal temperature was the highest. Since the temperatures in the different bedrooms were similar, only one bedroom from each floor has been chosen to represent the internal temperature variations.

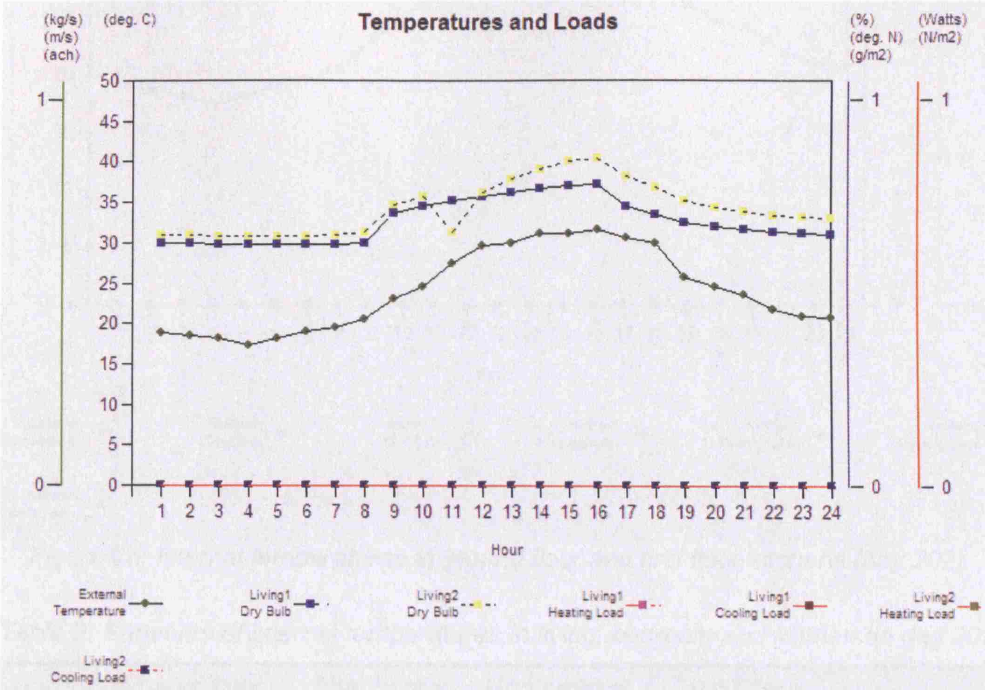


Figure 24: Internal temperatures in ground floor and first floor living rooms (day 202)

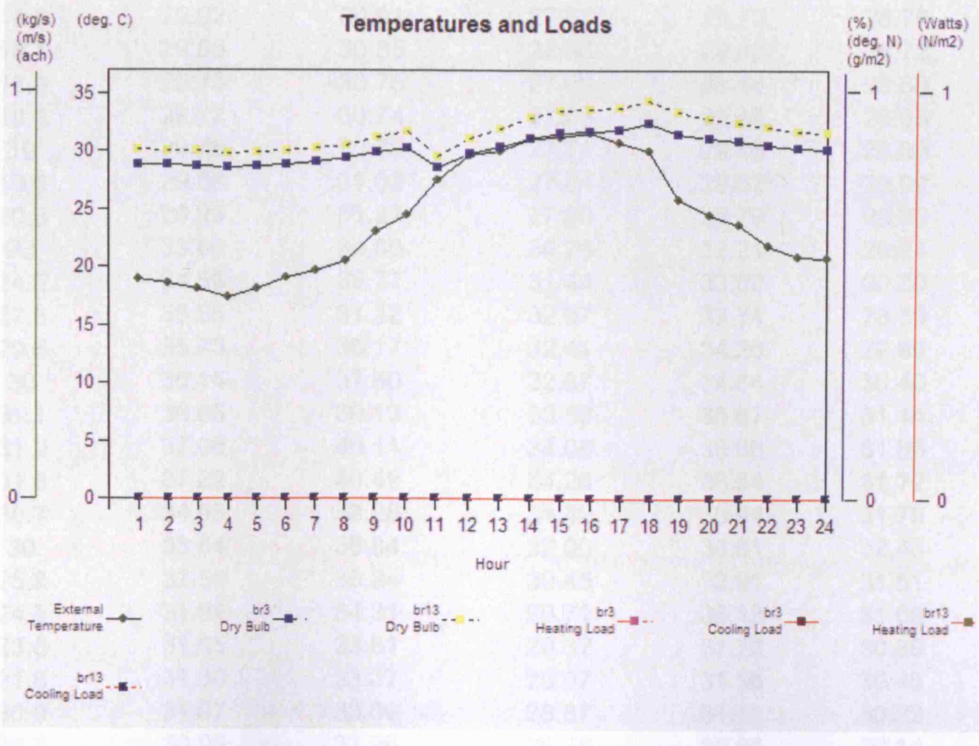


Figure 25: Internal temperatures in bedrooms 3 and 13 (day 202)

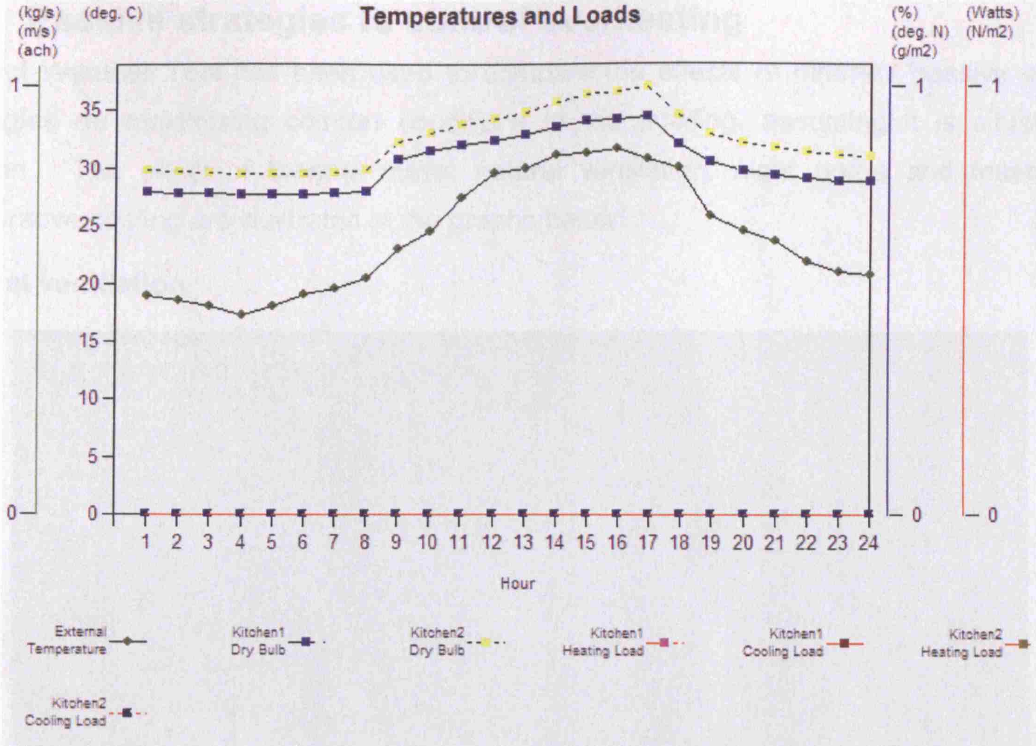


Figure 26: Internal temperatures in ground floor and first floor kitchens (day 202)

Table 9: Summary of internal temperatures in living, bedroom and kitchen on day 202

Hour	External Temp (oC)	Ground floor Living room Temp (oC)	First floor Living room Temp (oC)	Ground floor Kitchen Temp (oC)	First floor Kitchen Temp (oC)	Bedroom 3 Temp (oC)	Bedroom 13 Temp (oC)
1	18.9	30.01	30.99	27.95	29.82	28.86	30.09
2	18.6	29.92	30.91	27.87	29.72	28.79	30.02
3	18.1	29.85	30.85	27.80	29.62	28.72	29.95
4	17.3	29.73	30.75	27.69	29.49	28.58	29.82
5	18.1	29.72	30.74	27.68	29.46	28.65	29.86
6	19	29.76	30.79	27.71	29.48	28.82	29.99
7	19.6	29.86	31.02	27.84	29.62	29.09	30.22
8	20.5	29.99	31.27	27.99	29.79	29.39	30.51
9	23	33.66	34.66	30.73	32.21	29.94	31.17
10	24.5	34.58	35.77	31.44	33.00	30.30	31.64
11	27.5	35.25	31.32	32.07	33.74	28.59	29.47
12	29.6	35.73	36.17	32.41	34.26	29.80	31.13
13	30	36.14	37.80	32.87	34.84	30.40	31.93
14	31.1	36.65	39.13	33.56	35.67	31.14	32.87
15	31.2	37.06	40.11	34.08	36.36	31.63	33.51
16	31.6	37.22	40.49	34.20	36.64	31.72	33.62
17	30.7	34.55	38.28	34.42	36.94	31.79	33.71
18	30	33.54	36.84	32.00	34.61	32.40	34.34
19	25.8	32.56	35.24	30.45	32.91	31.51	33.40
20	24.5	31.99	34.31	29.71	32.13	31.06	32.84
21	23.6	31.65	33.81	29.37	31.72	30.80	32.47
22	21.8	31.30	33.37	29.07	31.36	30.45	32.01
23	20.9	31.07	33.09	28.87	31.11	30.22	31.73
24	20.7	30.96	32.96	28.78	30.98	30.14	31.64

6. Passive strategies to control overheating

Ecotect Weather Tool has been used to compare the effects of different passive cooling strategies on maximising comfort conditions in the building, assuming it is situated in London. The effect of thermal mass, natural ventilation, night purge and mass, and evaporative cooling are illustrated in the graphs below:

Natural ventilation

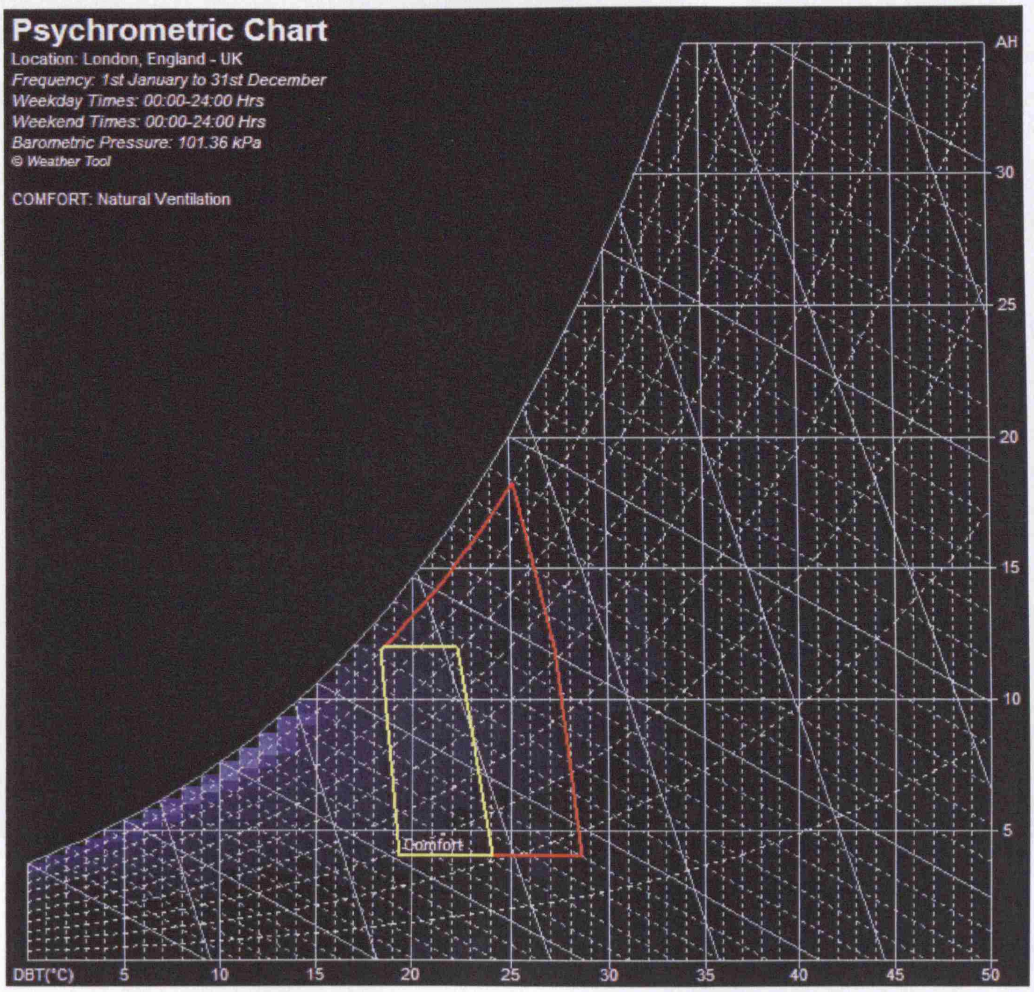


Figure 27: Psychrometric chart illustrating the effect of increasing natural ventilation

As can be seen from the Psychrometric chart, the effect of increasing natural ventilation within the building would stretch the comfort zone to cover areas of high and low humidity and high temperatures, hence the use of this passive strategy would help in controlling high temperatures and humidity in the building. Adequate natural ventilation can usually be provided by positioning windows and applying opening schedules so that cross ventilation is maximised. Stack ventilation can also be investigated in this case, since the building contains rooflights, which can be used as a means of escape for warm air from inside the building.

Thermal mass effect

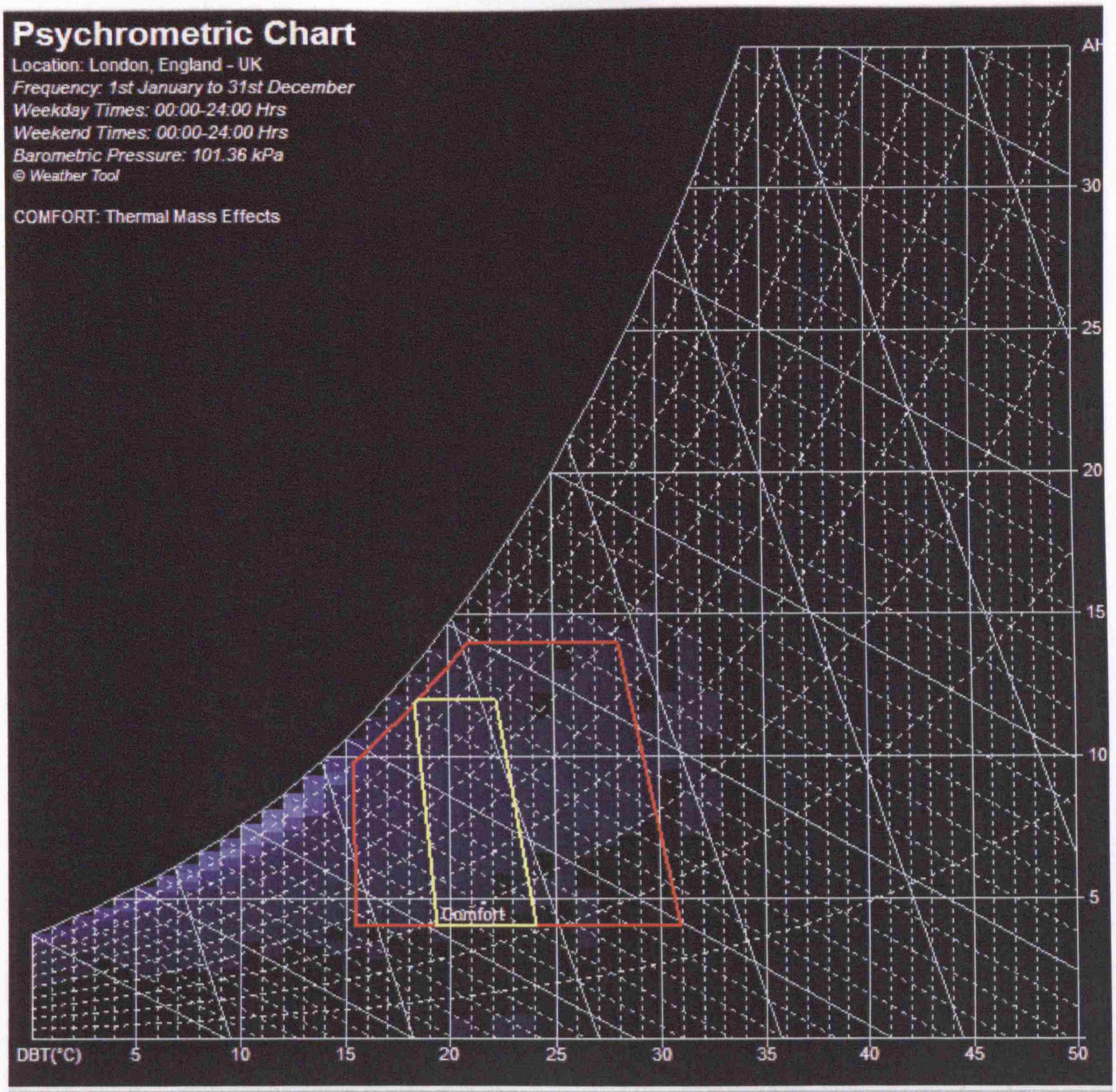


Figure 28: Psychrometric chart illustrating the effect of increasing thermal mass

Using materials with high thermal mass in the building envelope can be used to absorb heat during the day and release it at night, so that it can absorb heat again the following day. For thermal mass to be effective, it should be exposed to the living spaces and adequate insulation provided so that excess heat from outside does not enter the building, but heat trapped inside can be absorbed by the mass and be released at night when the temperature is cooler. An increase in thermal mass would therefore stabilise the temperature inside the building by cutting down the extreme temperatures and shifting the time of impact of high temperatures to a later time, when the internal temperature is lower.

Thermal mass and night ventilation

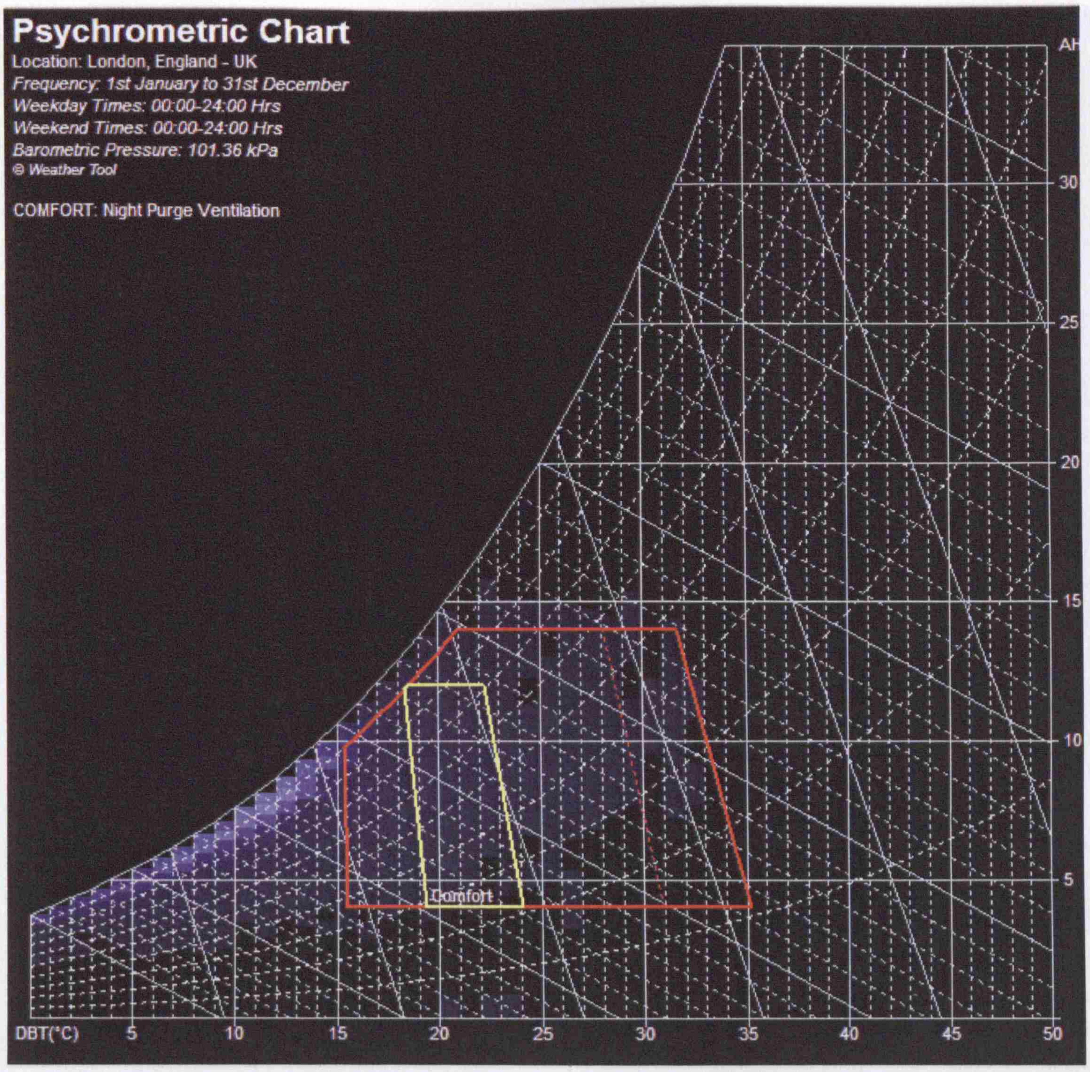


Figure 29: Psychrometric chart illustrating the effect of increasing thermal mass and night ventilation

This strategy relies on the daily heat storage capacity of the thermal mass, in combination with night ventilation to cool down the mass. For this strategy to be effective, the building should be closed during the day if the external temperature is higher than the internal temperatures, and opened at night to allow the mass to cool down and hence increase the heat absorption capacity of the structure for the following day.

Direct evaporative cooling

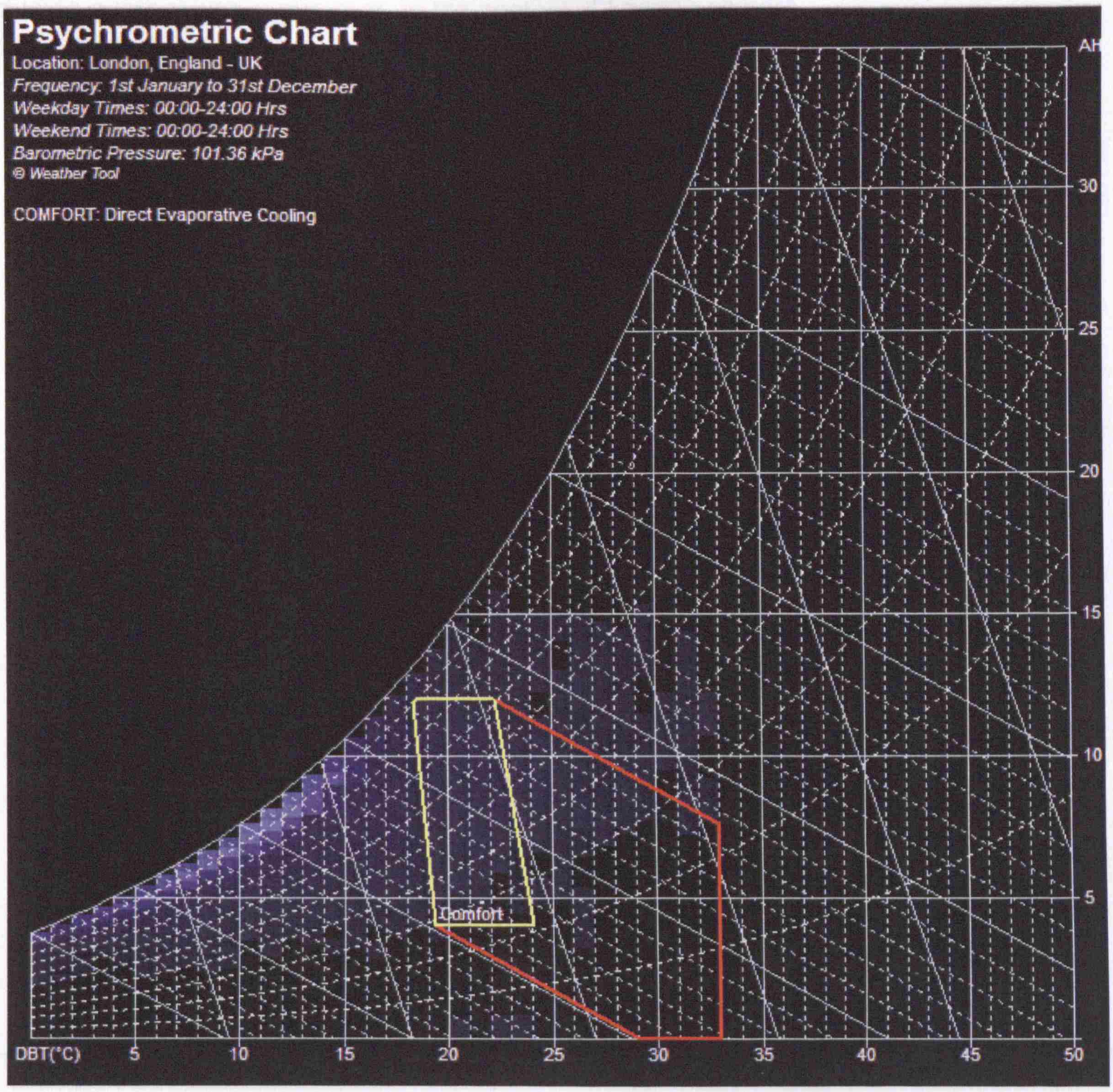


Figure 30: Psychrometric chart illustrating the effect of using direct evaporative cooling

Evaporative cooling lowers the internal air temperature by making use of the cooling effect of evaporating water. This technique is particularly effective in dry climates, and is usually carried out directly in the space to be cooled down (direct evaporative cooling). Indirect methods, such as roof ponds, can also be used, which allow evaporative cooling to be used in more temperate climates as well. Ventilation and evaporative cooling are often supplemented by mechanical means, such as fans, but these use substantially less energy as compared with air-conditioning/refrigeration systems.

The following graph shows a summary of the effects of the different passive strategies in reducing overheating in summer, in the context of London climate.

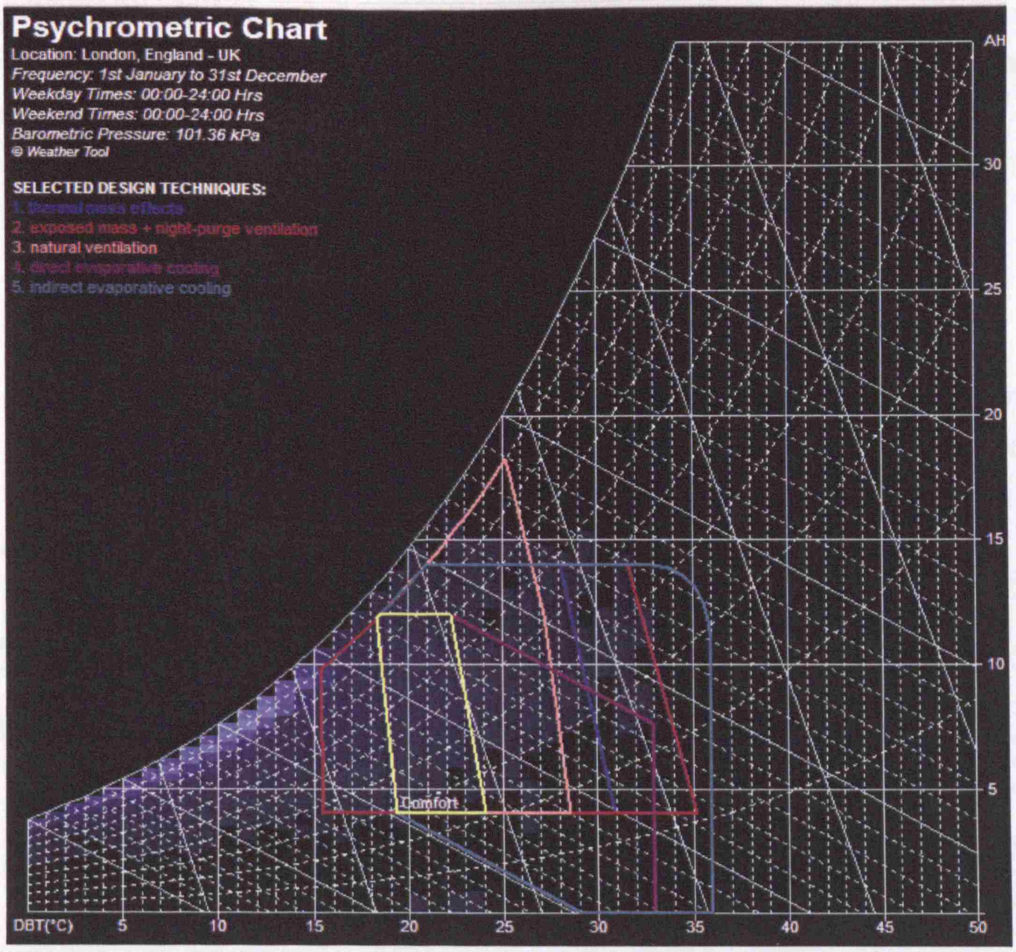


Figure 31: Summary of the effects of the different passive strategies

The chart below illustrates the percentage increase in comfort that can be achieved within the building using the selected passive strategies (thermal mass, exposed mass + night purge, natural ventilation, direct and indirect evaporative cooling).

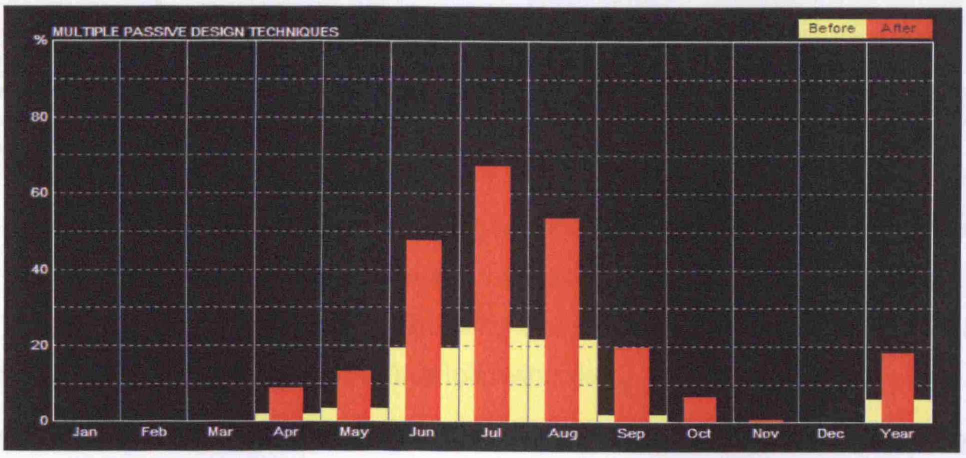


Figure 32: Chart illustrating the increase in comfort resulting from the different passive strategies

It can be seen that the above passive strategies can be very effective in controlling and reducing overheating in the summer by getting rid of the heat already trapped inside the building. However other measures can also be taken to modify the building so as to reduce heat gains in the first place, such as heat blocking windows, good shading from building elements and/or vegetation, high insulation levels, and proper solar orientation. The resulting effects of each of these strategies have been investigated by applying them to the model building in TAS, as described below.

6.1 Changes to building envelope

6.1.1 Shading and glazing type

Shading was provided on all windows by using horizontal louvers 0.5m wide and 0.2m deep, tilted 45° downwards and placed along the glass panels with a gap of 0.2m in between them. The glazing of the bedrooms, living room and kitchen have been replaced by a new one, as detailed below:

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m2 C)	Time Constant (hours)	External Blind	Internal Blind
	ext. surf.	int. surf.	int. surf.	ext. surf.		External	Internal				
0.021	0.424	0.220	0.564	0.080	0.060	0.120	0.845	0.982	0.000	NO	NO

Layer	M-Code	Wi...	Solar...	Ext ...	Int ...	Ext ...	Int ...	Con...	Con...	Vap...	Description
Inside	am1pilk\27	10.0	0.570	0.190	0.130	0.120	0.845	1.000	0.000	999...	10MM KAPPAFLOAT (NEUTRAL)
2	am1cav\1	10.0	0.000	0.000	0.000	0.000	0.000	0.000	2.500	1.000	10MM AIR (HORIZONTAL FLOW)
3	blind\22	1.0	0.090	0.560	0.560	0.850	0.850	1.000	0.000	1.000	opaque white, 60 angle
4	am1cav\1	10.0	0.000	0.000	0.000	0.000	0.000	0.000	2.500	1.000	10MM AIR (HORIZONTAL FLOW)
5	sgplan\4	6.0	0.585	0.220	0.080	0.080	0.845	1.000	0.000	999...	6mm SG planitherm low E
6	am1cav\4	20.0	0.000	0.000	0.000	0.000	0.000	0.000	1.270	1.000	20MM AIR (HORIZONTAL FLOW)
7	am1pilk\27	10.0	0.570	0.190	0.130	0.120	0.845	1.000	0.000	999...	10MM KAPPAFLOAT (NEUTRAL)

The details of the window pane chosen for the roof-light are as follows:

Transparent Construction   Name glass\3   Description Antisun green double glazing low E

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m2 C)	Time Constant (hours)	External Blind	Internal Blind
	ext. surf.	int. surf.	int. surf.	ext. surf.		External	Internal				
0.293	0.532	0.083	0.226	0.311	0.426	0.845	0.845	2.600	0.000	NO	NO

Layer	M-Code	Wid...	Sola...	Ext ...	Int ...	Ext ...	Int ...	Con...	Co...	Vap...	Description
Inside	am1pilk\26	6.0	0.630	0.200	0.150	0.120	0.845	1.000	0.000	999...	6MM KAPPAFLOAT (NEUTRAL)
2	am1cav\2	12.0	0.000	0.000	0.000	0.000	0.000	0.000	2.080	1.000	12MM AIR (HORIZONTAL FLOW)
3	am1pilk\8	6.0	0.460	0.050	0.050	0.845	0.845	1.000	0.000	999...	6MM ANTISUN (BRONZE)

The roof-light has been set to be constantly open, so that heat accumulated from the first floor can be exhausted through the roof vents. This will also encourage night ventilation, whereby cooler air at night will enter the building and cool down the structure so that its absorption capacities are increased for the following day.

Since rooms of the first floor are more prone to overheating, this strategy is seen to have a positive effect on controlling overheating in the rooms of this floor.

Resulting internal temperatures

With the above changes applied, the following internal temperatures were obtained in the living room, bedrooms and kitchen on day 202 (21st July):

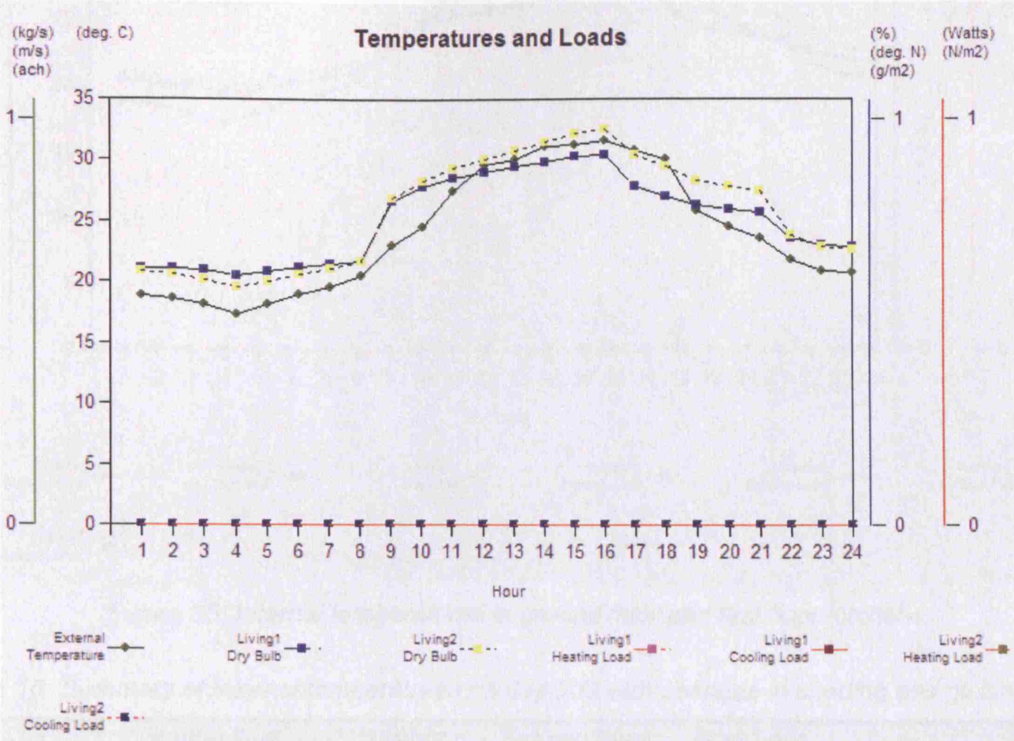


Figure 33: Internal temperatures in ground floor and first floor living rooms

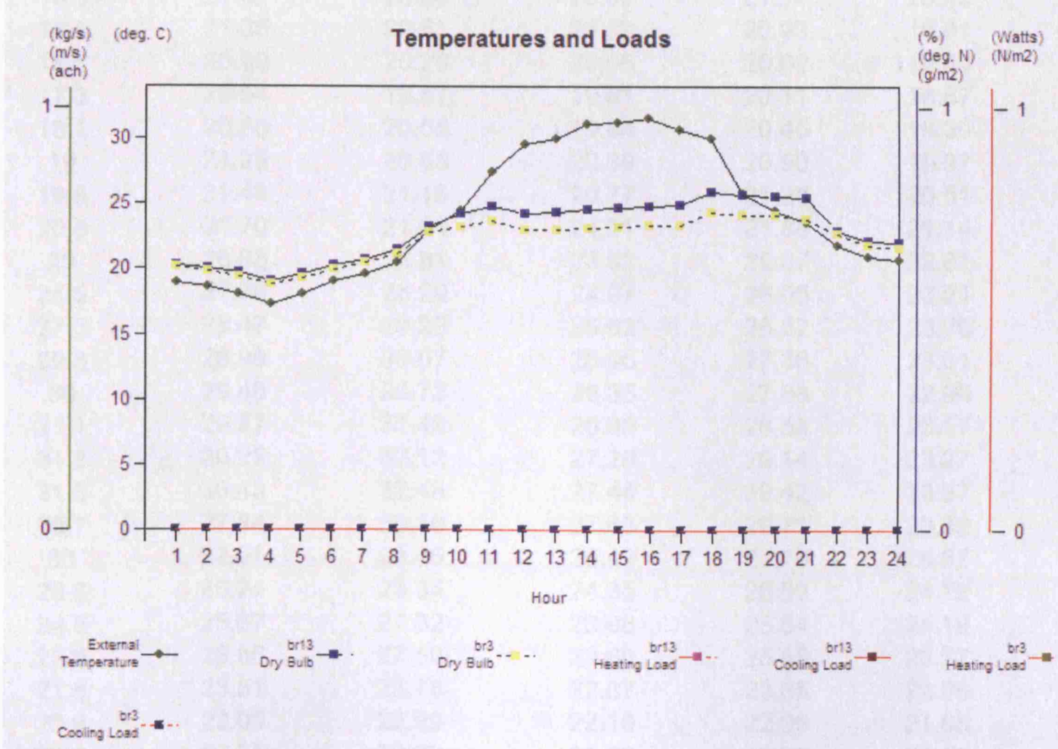


Figure 34: Internal temperatures in bedrooms 3 and 13

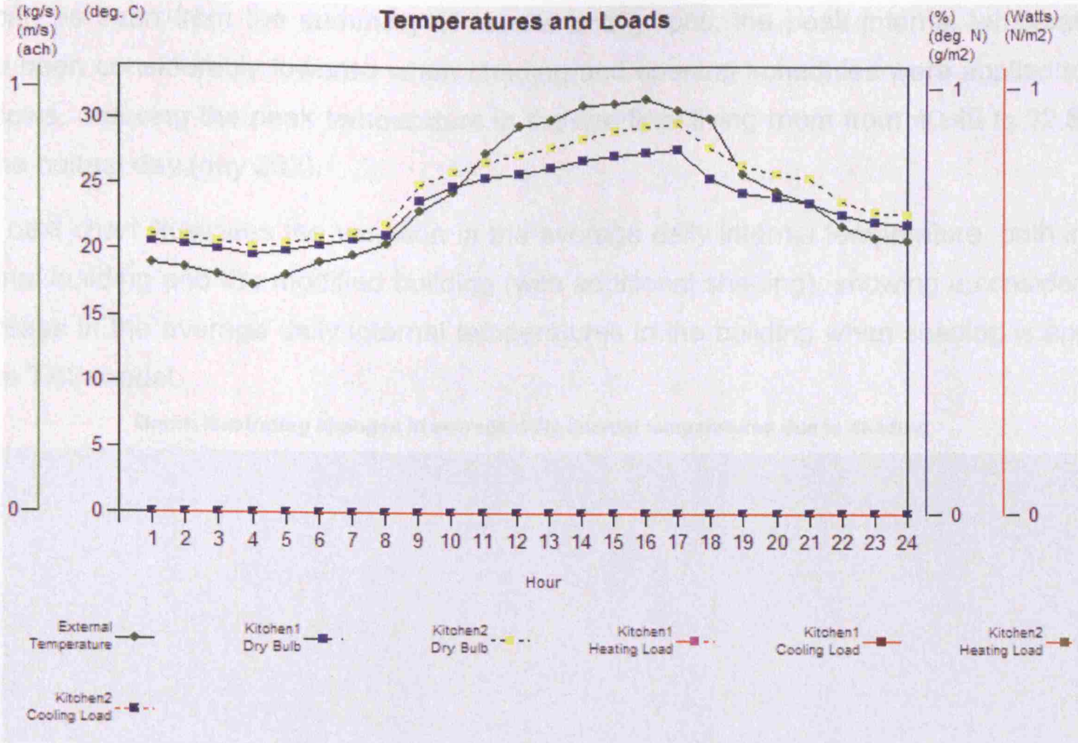


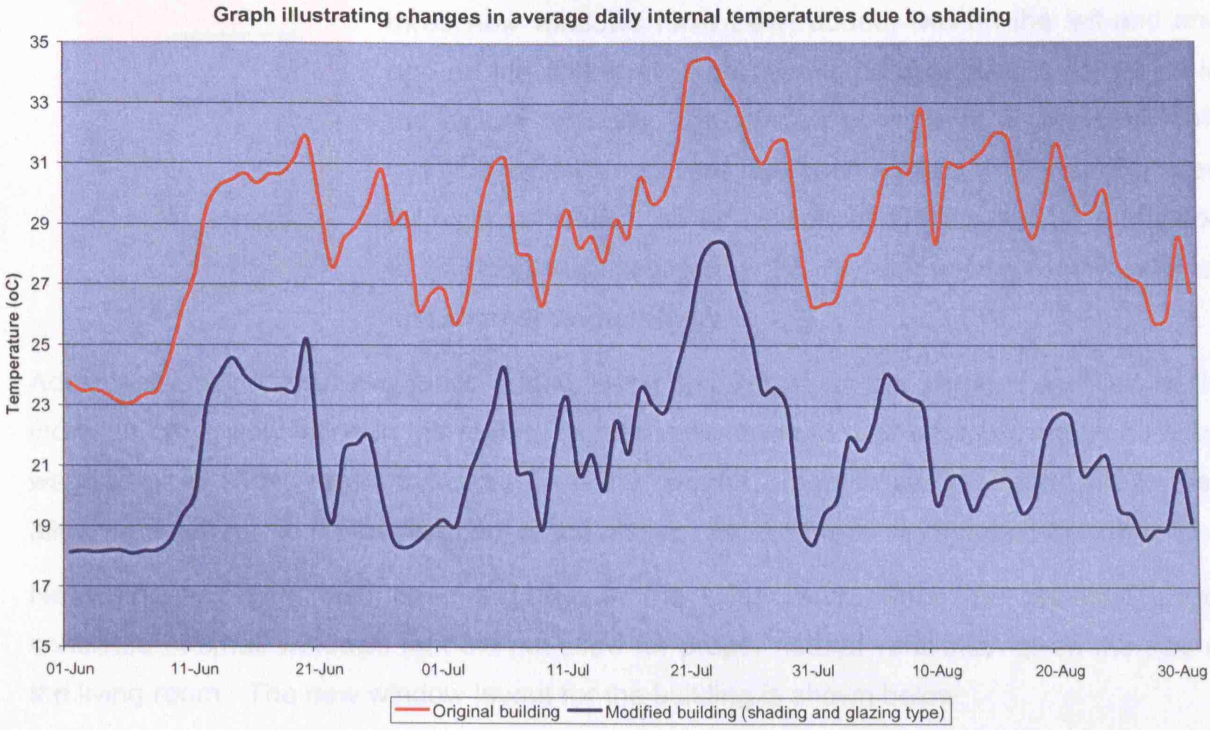
Figure 35: Internal temperatures in ground floor and first floor kitchens

Table 10: Summary of internal temperatures on day 202 with changes in shading and glazing type

Hour	External Temp. (oC)	Ground floor Living room Temp (oC)	First floor Living room Temp (oC)	Ground floor Kitchen Temp (oC)	First floor Kitchen Temp (oC)	Bedroom 3 Temp (oC)	Bedroom 13 Temp (oC)
1	18.9	21.07	20.84	20.59	21.14	20.12	20.30
2	18.6	21.05	20.61	20.38	20.93	19.81	20.06
3	18.1	20.99	20.20	20.08	20.62	19.40	19.68
4	17.3	20.54	19.57	19.61	20.11	18.87	19.05
5	18.1	20.86	20.05	19.94	20.45	19.30	19.60
6	19	21.25	20.65	20.39	20.90	19.97	20.23
7	19.6	21.46	21.15	20.77	21.28	20.51	20.70
8	20.5	21.70	21.64	21.21	21.88	21.14	21.49
9	23	26.63	26.81	23.82	25.07	22.81	23.30
10	24.5	27.78	28.29	24.97	26.05	23.21	24.24
11	27.5	28.47	29.29	25.62	26.82	23.70	24.78
12	29.6	28.99	30.07	25.96	27.36	23.01	24.27
13	30	29.40	30.72	26.35	27.88	22.99	24.32
14	31.1	29.87	31.49	26.90	28.58	23.17	24.55
15	31.2	30.25	32.12	27.29	29.14	23.27	24.71
16	31.6	30.43	32.48	27.44	29.42	23.37	24.86
17	30.7	27.84	30.36	27.63	29.71	23.32	24.87
18	30	27.01	29.45	25.49	27.79	24.37	25.86
19	25.8	26.24	28.34	24.35	26.50	24.12	25.66
20	24.5	25.87	27.82	23.98	25.84	24.19	25.56
21	23.6	25.66	27.50	23.60	25.45	23.77	25.49
22	21.8	23.51	23.78	22.67	23.65	22.65	22.97
23	20.9	22.93	22.89	22.10	22.96	21.85	22.18
24	20.7	22.85	22.63	21.92	22.75	21.62	21.99

As can be seen from the summary of results and graphs, the peak internal temperatures have been considerably lowered when shading and opening schedules were applied to the windows, reducing the peak temperature in the first floor living room from 40.49 to 32.57 °C on the hottest day (day 202).

The next chart illustrates the variation in the average daily internal temperature, both in the original building and the modified building (with additional shading), showing a considerable decrease in the average daily internal temperatures in the building when shading is applied to the TAS model.



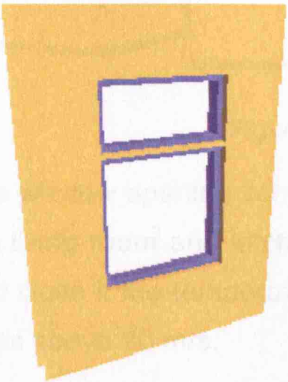
6.1.2 Thermal mass

The wall and roof constructions in the existing building already have good thermal mass properties. Changing the wall properties to include more mass was found not to make much difference, therefore the existing thermal mass in the building envelope can be assumed to be appropriate and has been unchanged. The point to be noted is that thermal mass can be ineffective if the external temperature remains constantly high for consecutive days and the mass is not allowed to cool down. Hence, the inclusion of thermal mass as a passive design feature is usually coupled with appropriate ventilation, especially night ventilation.

The next modification will therefore take into consideration night ventilation as an aid in cooling down the thermal mass for better performance.

6.1.3 Further increase in natural ventilation and night purge

The effect of natural ventilation and night purge has been investigated in (1) above by applying some window opening schedules to the existing openings and allowing for some night purge through the rooflights. However, from the layout of the building, it can be seen that natural ventilation can be further encouraged by placing additional windows in corridor to allow for better cross ventilation, especially in rooms located on the ground floor, which cannot make use of stack ventilation.



In addition to the existing windows in the ends of the corridor, three new windows have been added, two on the left-end and one on the right end. The new corridor window is as shown in the picture opposite. The window consists of a normal window (w11) to which a top vent has been added, which can be used for night ventilation, while the bottom window can be scheduled to be open or closed during the day, depending on the external and internal temperatures.

Additionally, windows have been added along the length of the corridor wall, so as to increase cross ventilation in the rooms. Air movement would thus be improved by allowing warmer air to escape from the rooms into the corridor, where cross ventilation would then allow the warm air to be released out of the corridor windows and be replaced by cooler air.

New windows have also been included in the living room, since the previous layout consisted of small windows that did not allow for proper natural ventilation given the size of the living room. The new window layout for the building is shown below:

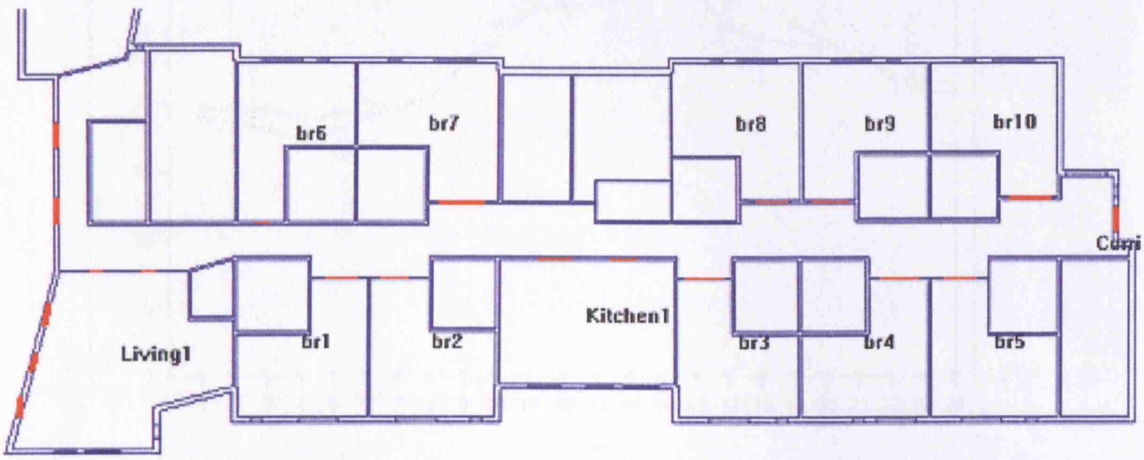


Figure 36: Ground floor plan showing added windows in red

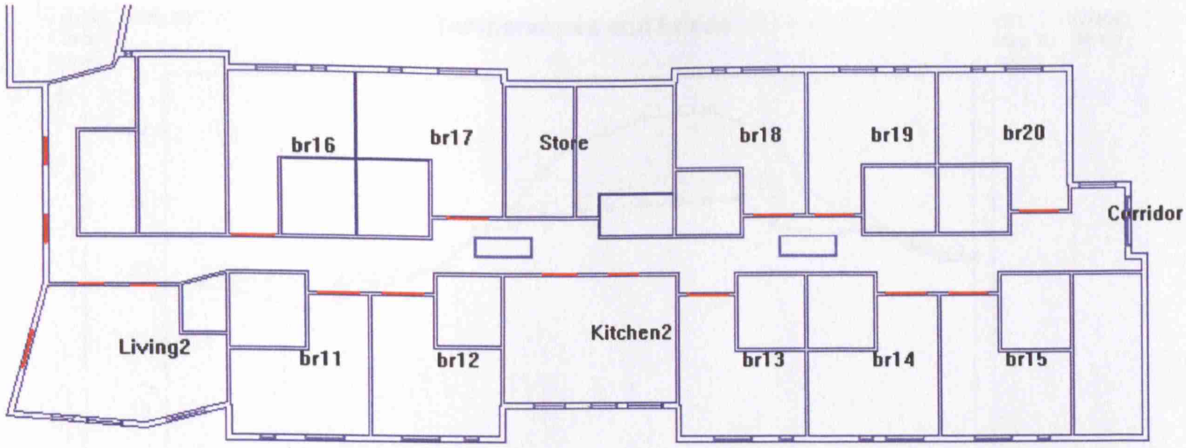


Figure 37: First floor plan showing added windows in red

The window opening schedule (zdwom) have been used and set so that the new windows in the living room and kitchen and bedrooms start opening at 17 °C, are fully open at 18 °C, and close if the temperature goes beyond 24 °C (cut-off temperature) and if the wind speed goes above 20 m/s.

The top vent of the corridor window has been scheduled to be kept open 24 hours a day during the summer period so as to allow for cross ventilation and night purge.

With this new window layout and in addition to the shading and opening schedules, the resulting temperatures in the bedrooms, kitchens and living rooms are as follows:

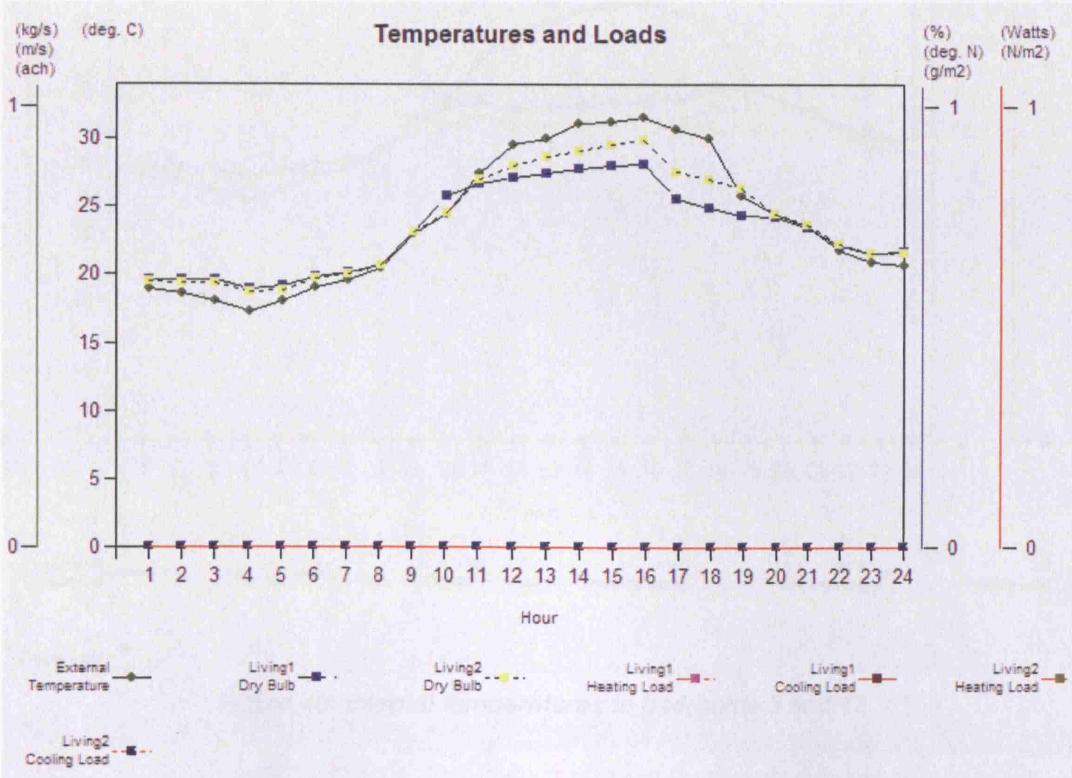


Figure 38: Ground floor and first floor living room temperatures

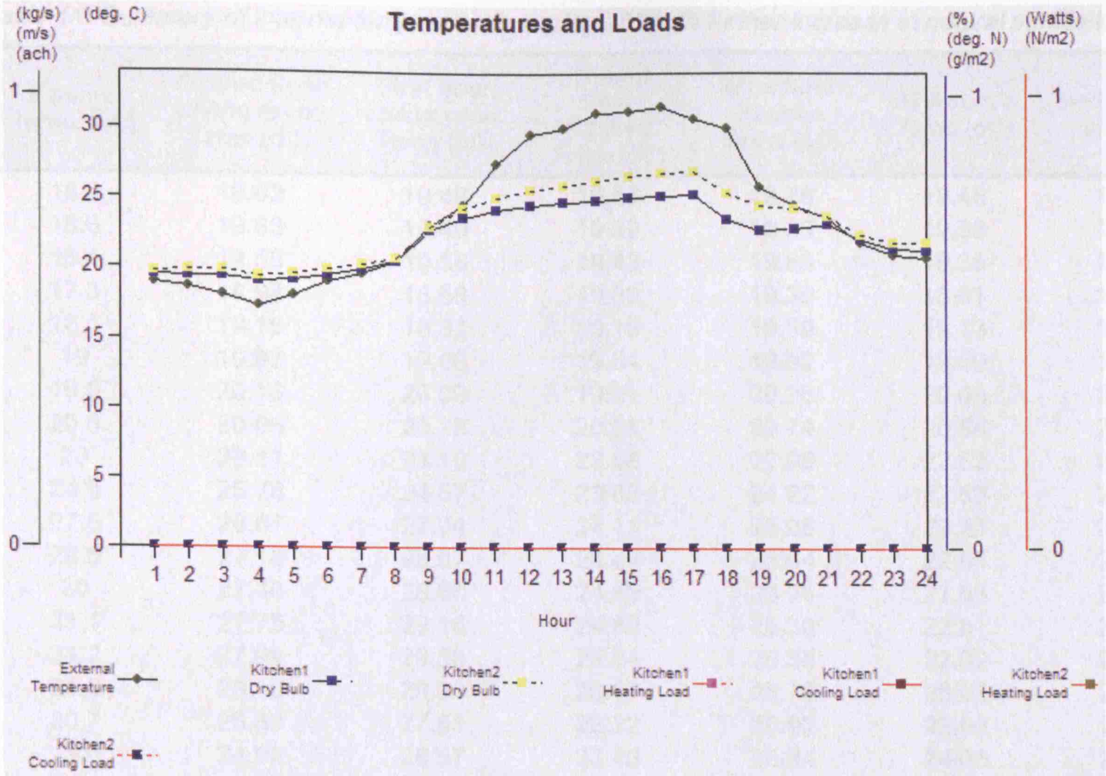


Figure 39: Internal temperatures in ground floor and first floor kitchens

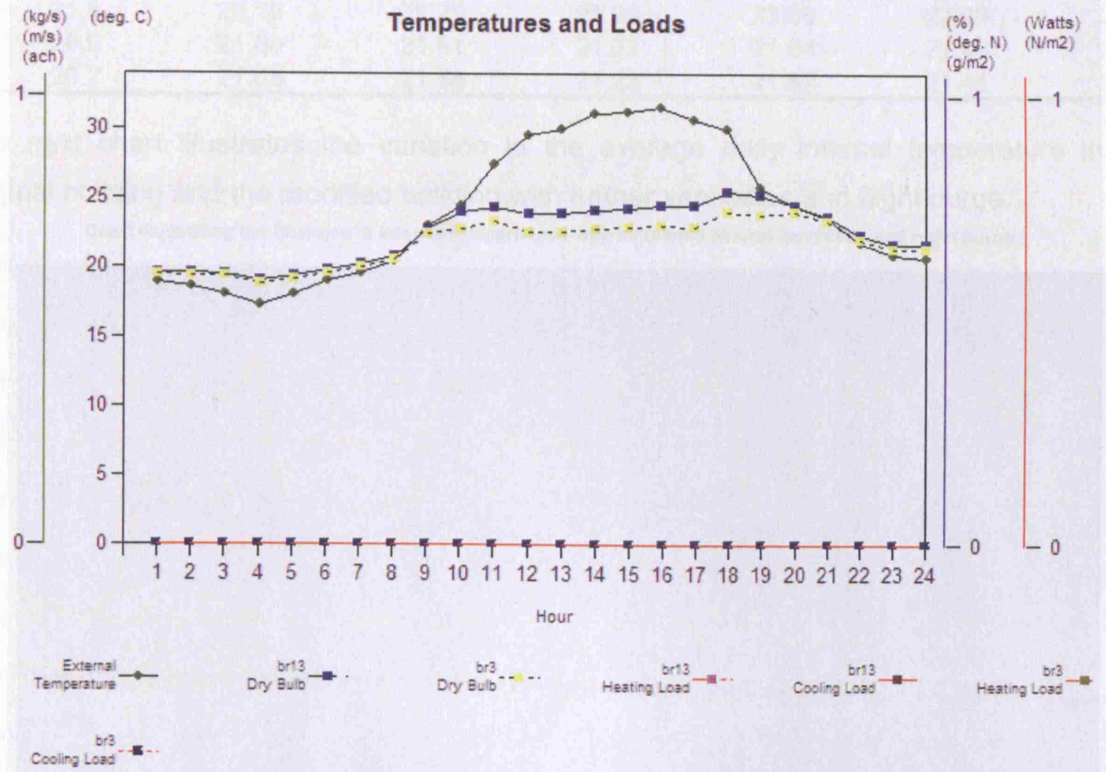
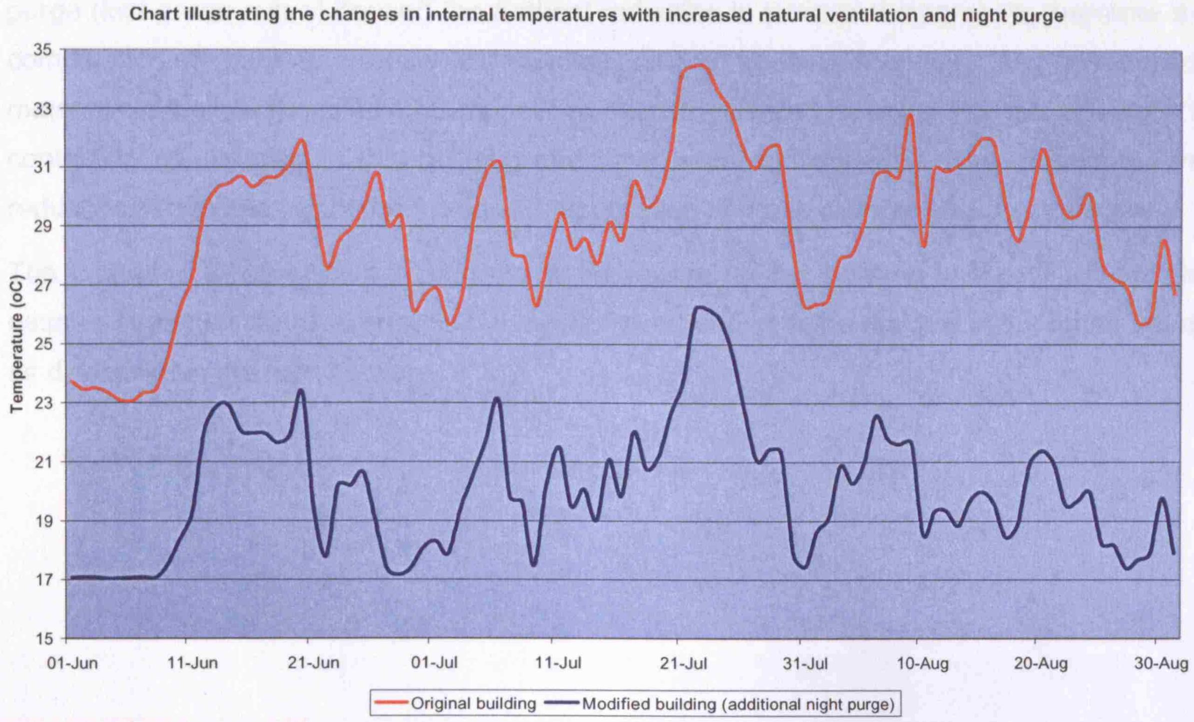


Figure 40: Internal temperatures in bedrooms 3 and 13

Table 11: Summary of internal temperatures on day 202 with further increase in natural ventilation

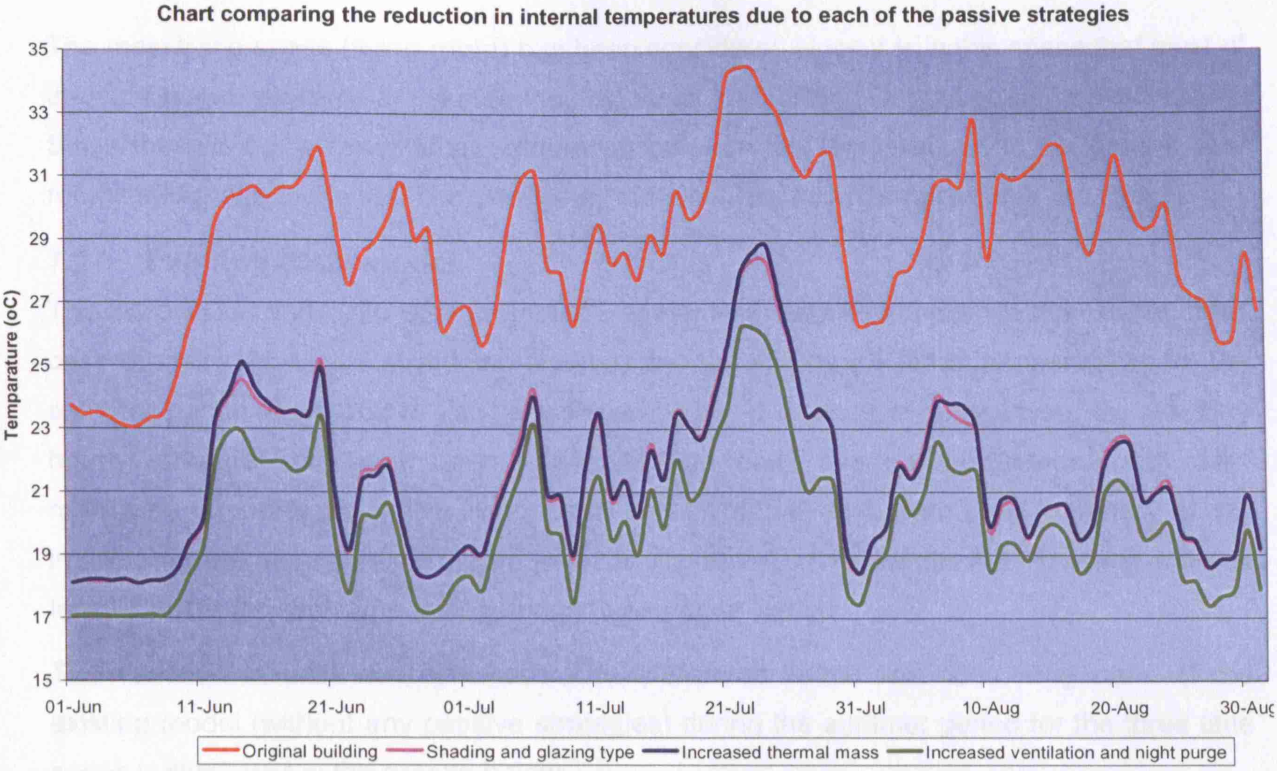
Hour	External Temp. (oC)	Ground floor Living room Temp (oC)	First floor Living room Temp (oC)	Ground floor Kitchen Temp (oC)	First floor Kitchen Temp (oC)	Bedroom 3 Temp (oC)	Bedroom 13 Temp (oC)
1	18.9	19.62	19.49	19.46	19.76	19.45	19.62
2	18.6	19.63	19.40	19.39	19.80	19.38	19.63
3	18.1	19.55	19.36	19.43	19.83	19.35	19.54
4	17.3	18.98	18.68	19.02	19.39	18.81	19.00
5	18.1	19.18	18.82	19.18	19.59	19.13	19.35
6	19	19.82	19.69	19.54	19.92	19.60	19.84
7	19.6	20.16	20.09	19.91	20.26	20.03	20.25
8	20.5	20.66	20.72	20.51	20.74	20.64	20.79
9	23	23.11	23.10	22.68	22.98	22.52	22.80
10	24.5	25.78	24.57	23.62	24.22	22.83	24.00
11	27.5	26.67	27.04	24.11	25.08	23.33	24.38
12	29.6	27.18	28.07	24.47	25.64	22.64	23.87
13	30	27.46	28.65	24.65	25.96	22.63	23.90
14	31.1	27.75	29.16	24.86	26.30	22.81	24.14
15	31.2	27.99	29.58	25.04	26.58	22.92	24.29
16	31.6	28.18	29.90	25.17	26.79	23.03	24.44
17	30.7	25.53	27.61	25.22	26.92	22.98	24.44
18	30	24.92	26.97	23.43	25.34	24.03	25.43
19	25.8	24.40	26.32	22.68	24.52	23.77	25.22
20	24.5	24.24	24.51	22.84	24.28	24.05	24.46
21	23.6	23.50	23.72	23.13	23.66	23.41	23.75
22	21.8	22.19	22.29	21.99	22.39	22.09	22.35
23	20.9	21.60	21.61	21.32	21.84	21.43	21.75
24	20.7	21.65	21.58	21.23	21.87	21.41	21.74

The next chart illustrates the variation in the average daily internal temperature in the original building and the modified building with further ventilation and night purge.



It can be seen that further promotion of natural ventilation and night purge, in conjunction with adequate window opening schedules, shading and thermal mass, caused a further decrease in internal temperatures in all of the rooms.

The next chart compares the effects that each of the strategies had in reducing internal temperatures.



The chart clearly shows that the combination of shading, increased thermal mass and night purge (last green curve) caused the furthest reduction in internal temperature; therefore the combination of parameters used for shading, window opening schedules and construction materials in the last modified TAS model has been considered as being the best approach to controlling overheating in this building and have been consequently used to estimate the reduction in overheating in the future with application of those passive cooling strategies.

The projected weather files have then been applied to the building with and without the passive strategies so as to assess the level of overheating in the building in the future years, as discussed in the next section.

7. Overheating in the future time-series

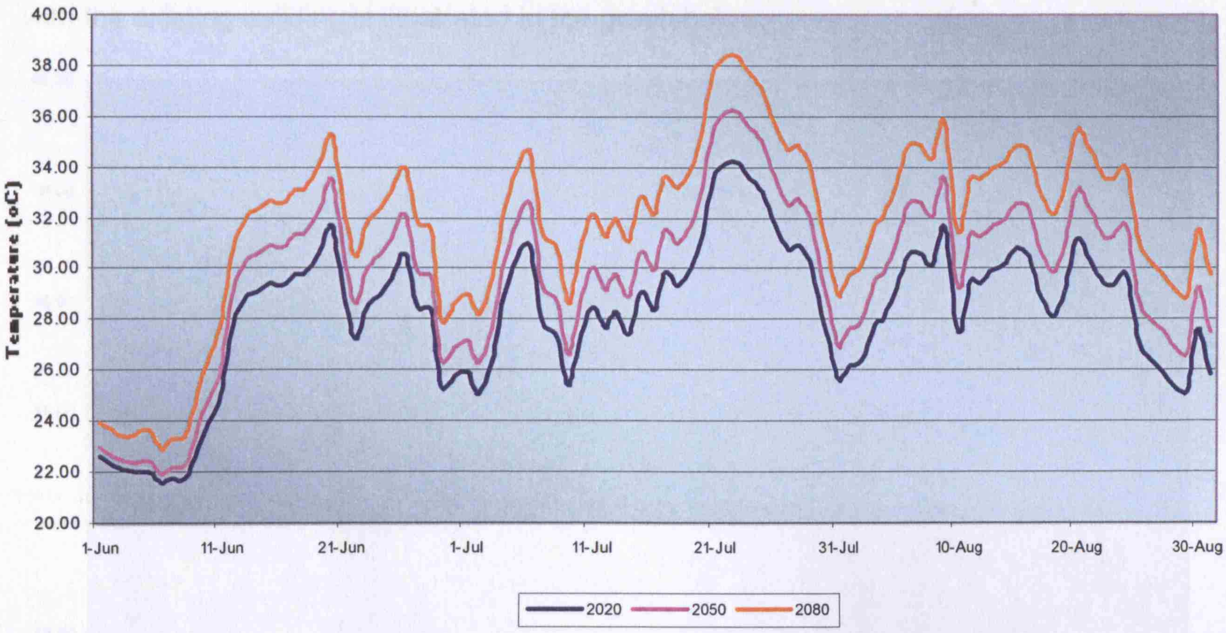
Using the building parameters specified in the previous section (shading, window opening schedules, construction materials, etc.), which caused the least external temperatures, the projected weather files have been applied to the TAS model and the resulting internal temperatures compared.

The main living space (living room) has been considered since it is in this space that most of the care home residents are during the day, when the building is most prone to overheating. Since there is not any significant difference between the temperatures in the ground floor rooms and those of the first floor, only the first floor living room temperatures are shown.

7.1 Existing case model

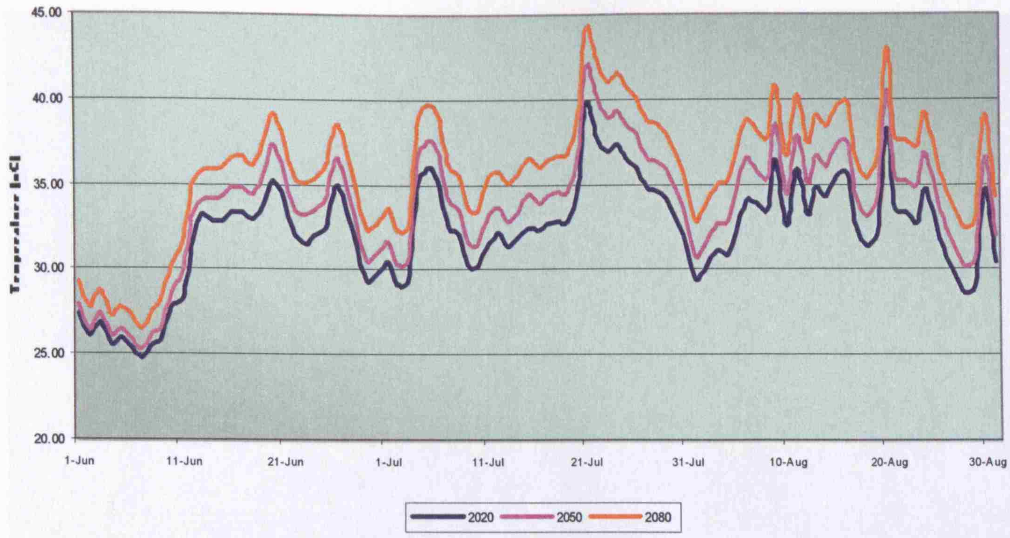
The 2020, 2050 and 2080 DSY projected weather files were first applied to the existing base case model (no passive strategies applied) and the resulting internal temperatures for the summer period (days 152 to 243) are shown below. For ease of comparison, the resulting hourly temperatures have been converted into daily average temperature and daily maximum temperature in the living room kitchen during this period. A summary of the internal temperatures in the living room is illustrated in Appendix A.1, showing internal temperatures for each time series during the summer period.

The variation in *daily average internal temperatures* in the first floor living room of the existing model (without any passive strategies) during the summer period for the three time series is illustrated in the graphs below:



Graph comparing daily average internal temperatures in future years in the existing case model

The next graph shows the variation in *daily maximum temperatures* in the first floor living room for the three time series:

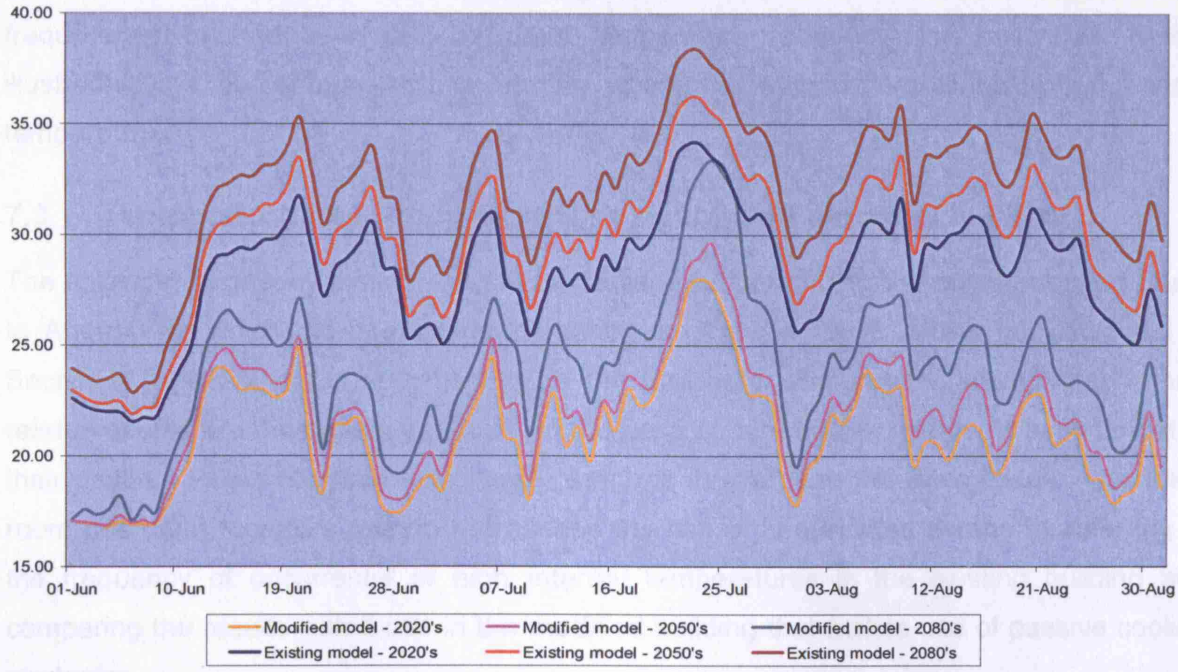


Graph comparing daily maximum internal temperatures in future years in the existing case model

7.2 Modified case model (inclusion of passive cooling techniques)

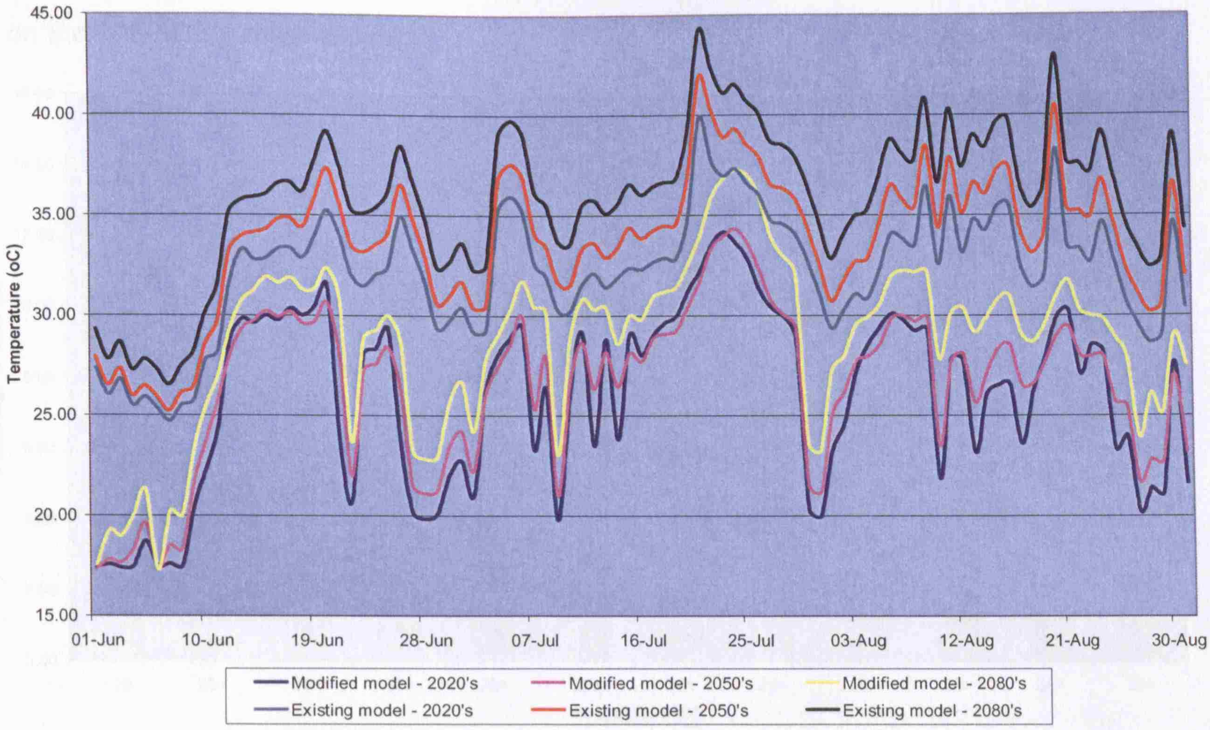
The 2020, 2050 and 2080 DSY projected weather files were then applied to the modified case model, with the inclusion of passive cooling strategies and window opening schedules that resulted in the least overheating in the building, as described in the previous chapters. The resulting internal temperatures for the summer period for each of the future time series are shown in Appendix A.2.

The variation in *daily average internal temperatures* in the modified building in comparison with the existing building is illustrated in the graph below:



Graph comparing daily *average* internal temperatures in future years in modified and existing case model

The next graph shows the variation in *daily maximum temperatures* in the existing building and modified building in the 2020's, 2050's and 2080's:



Graph comparing daily *maximum* internal temperatures in future years in the modified and existing case model

From the graph, it can be seen that internal temperatures are significantly reduced with the application of the passive cooling strategies. However, it is also clear that, even with the application passive strategies such as natural ventilation, proper shading and insulation, overheating will still remain a problem on some particularly hot days, and this is going to be even more pronounced in the future due to global warming. To have a better estimate of the frequency of occurrence of very hot days, temperature frequency plots have been made, illustrating the percentage of time during which the temperature is beyond threshold temperature.

7.3 Temperature frequency plots for existing and modified building

The following frequency plots show the percentage of time during the summer period (June to August) for which the internal temperatures was above 25 °C, which, as explained in Section 2.5 previously, is assumed to be the threshold temperature beyond which heat-related deaths are most likely to occur. In the case of care homes, residents spend most of their daytime in the common living area, which is in this case the living room. The living room has been therefore selected to assess the risk of heat-related deaths by referring to the frequency of occurrence of high internal temperatures in the existing building and comparing the results with those in the modified building that makes use of passive cooling strategies.

7.3.1 Base case: 1989 DSY

The following graph illustrates the temperature frequency plot for the existing building based on the 1989 DSY climate data:

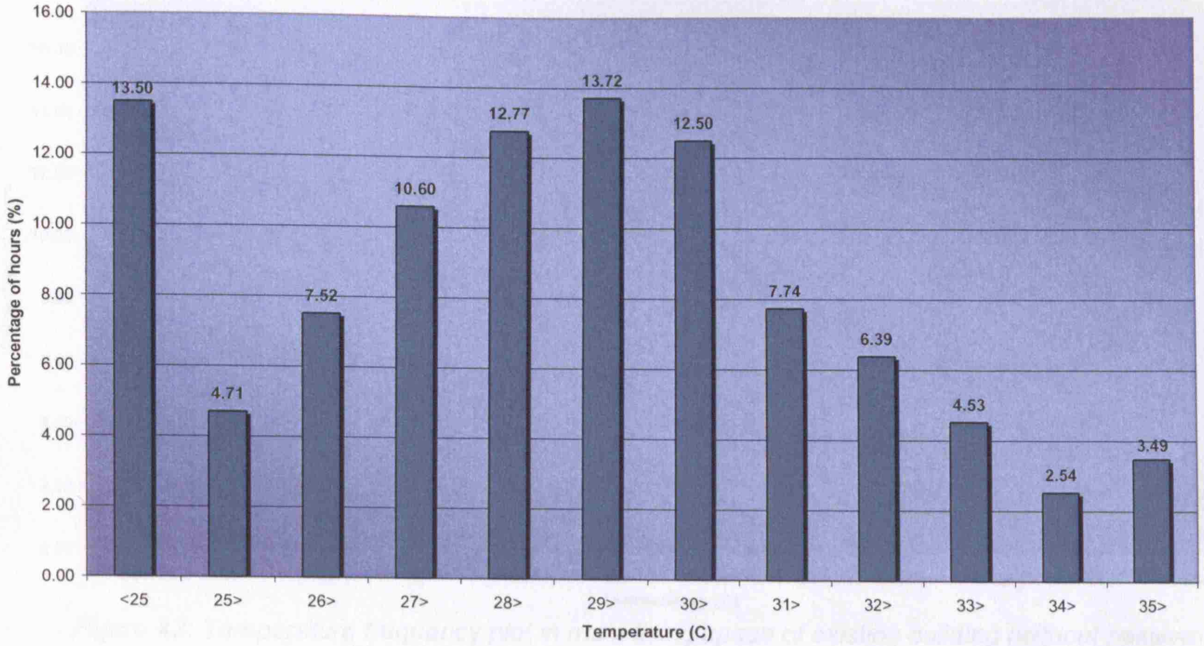


Figure 41: Temperature frequency plot in main living space of existing building (without passive cooling strategies) during the summer period of 1989 DSY

The next graph illustrates the temperature frequency plot for the modified building (with application of passive strategies) based on the 1989 DSY climate data:

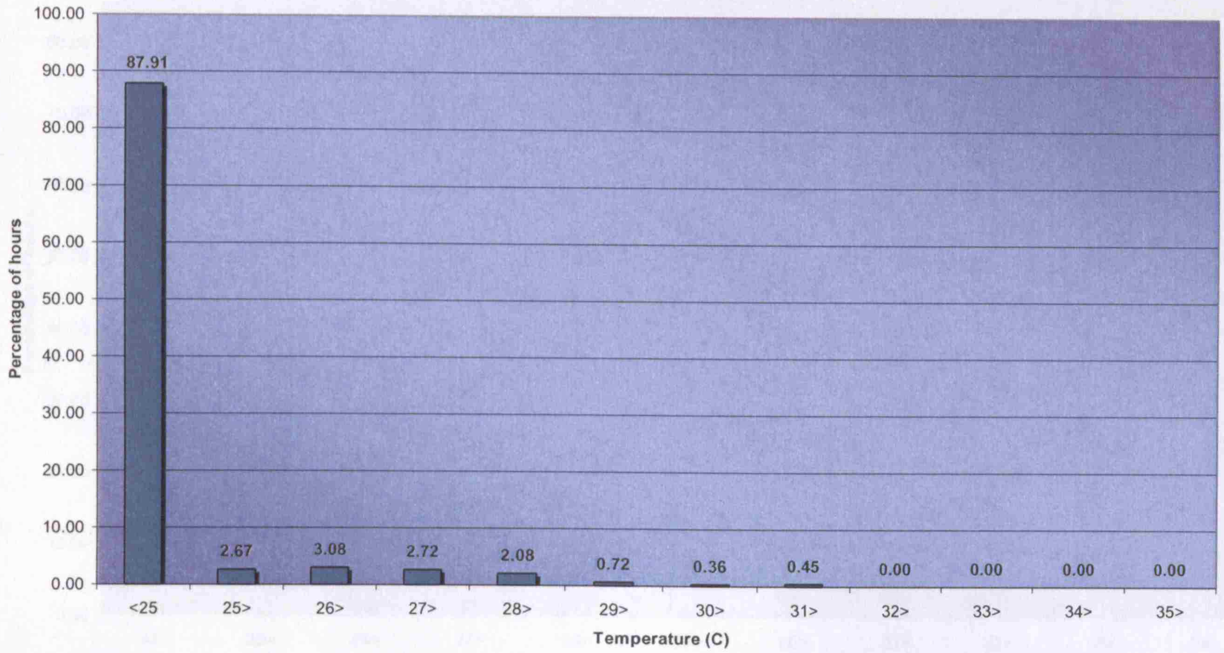


Figure 42: Temperature frequency plot in main living space of modified building (with passive cooling strategies) during the summer period of 1989 DSY

7.3.2 2020's time series

The following graph illustrates the temperature frequency plot for the existing building based on the projected climate data for the 2020's time series:

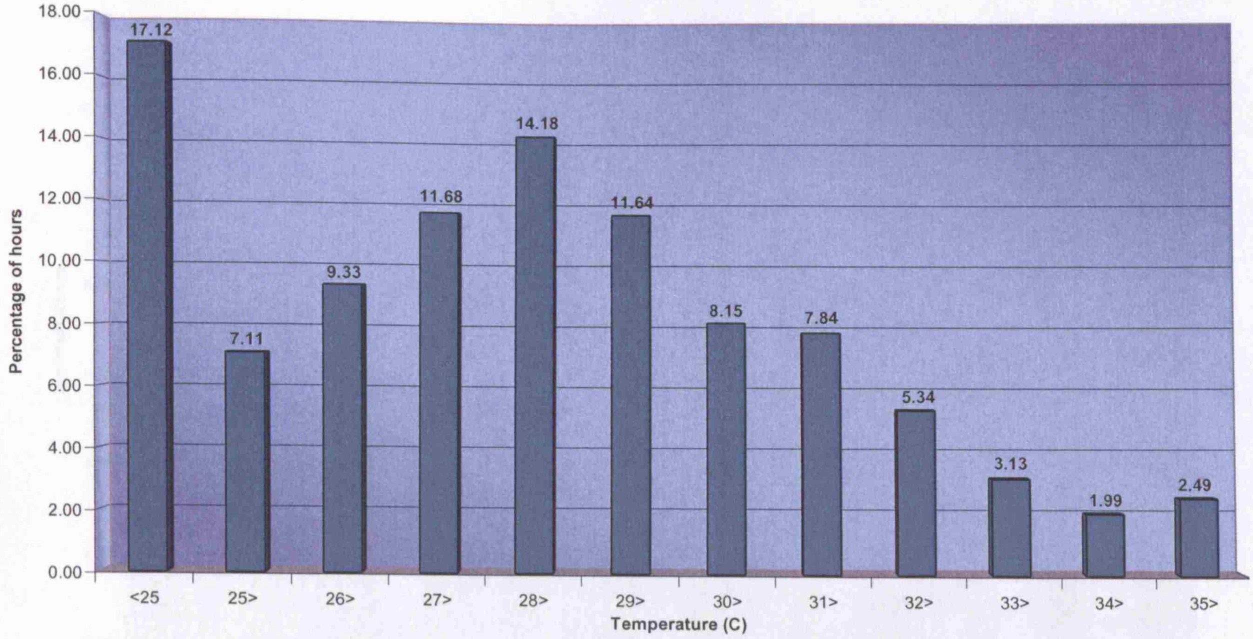


Figure 43: Temperature frequency plot in main living space of existing building (without passive cooling strategies) during the summer period of projected year 2020

The next graph illustrates the temperature frequency plot for the modified building (with application of passive strategies) based on the 2020's projected climate data:

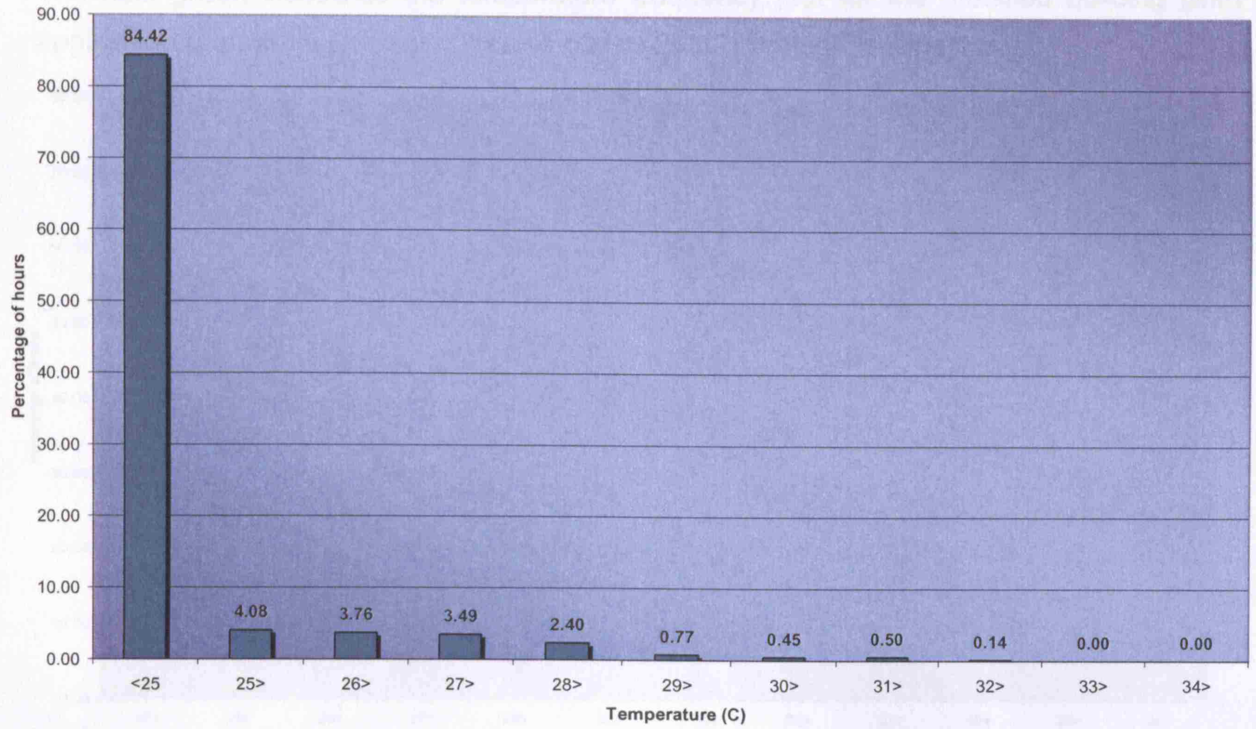


Figure 44: Temperature frequency plot main living space of modified building (with passive cooling strategies) during the summer period of projected year 2020

7.3.3 2050's time series

The following graph illustrates the temperature frequency plot for the existing building based on the projected climate data for the 2050's time series:

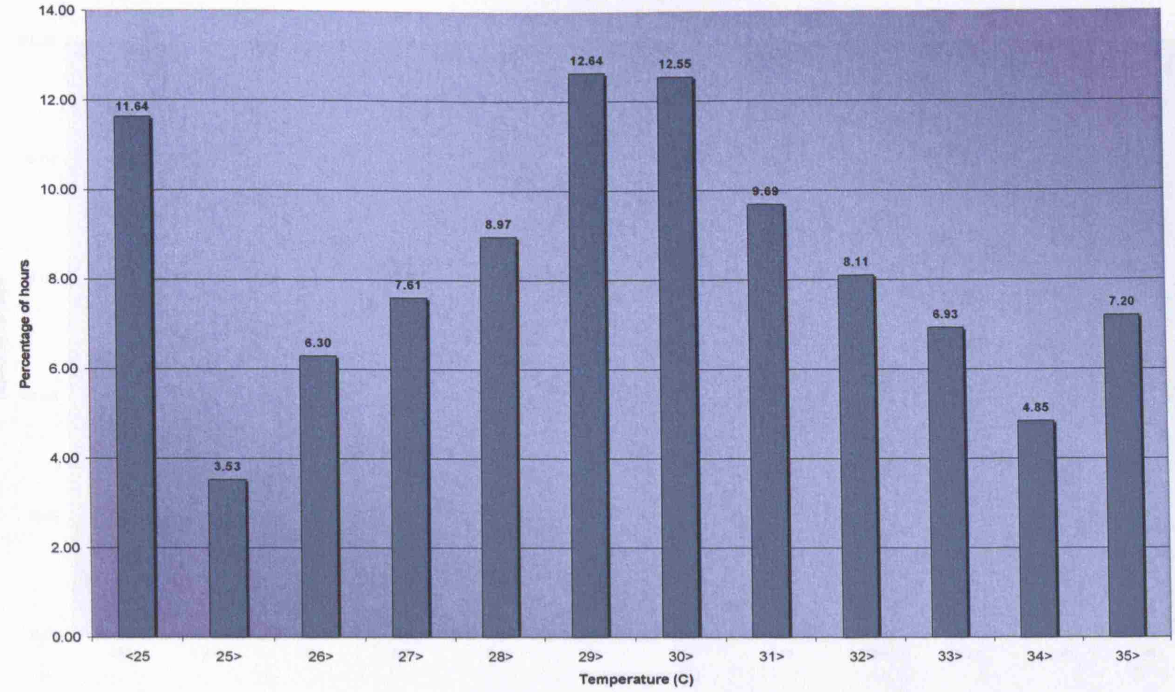


Figure 45: Temperature frequency plot in main living space of existing building (without passive cooling strategies) during the summer period of projected year 2050

The next graph illustrates the temperature frequency plot for the modified building (with application of passive strategies) based on the 2050's projected climate data:

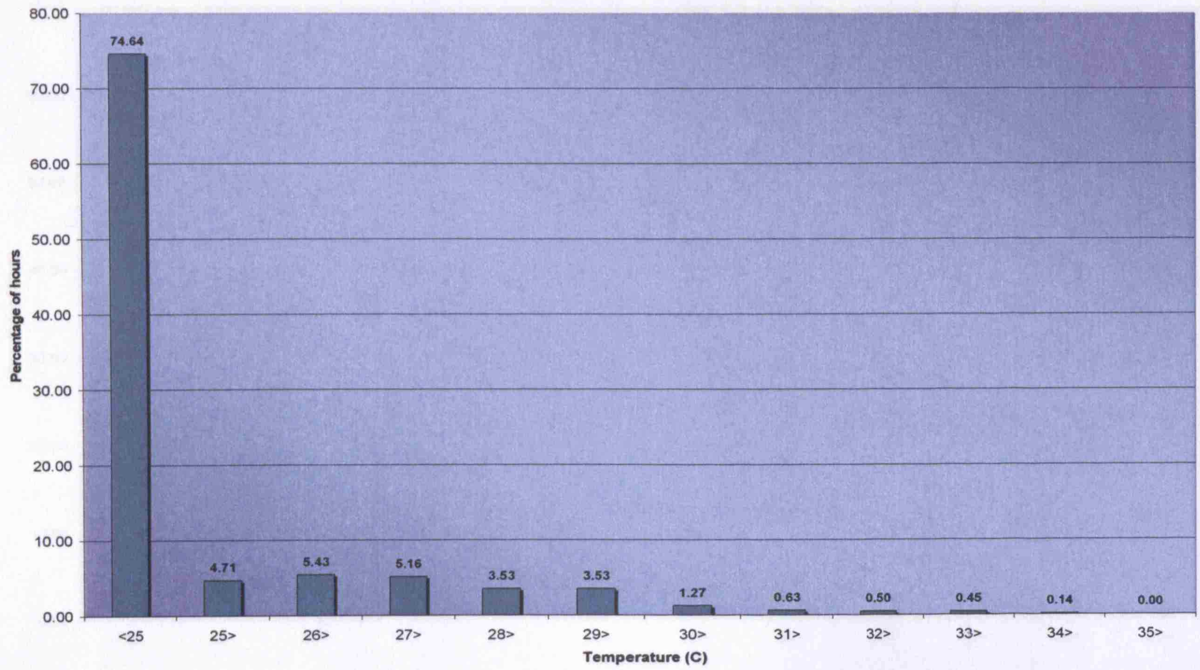


Figure 46: Temperature frequency plot in modified building (with passive cooling strategies) during the summer period of projected year 2050

7.3.4 2080's time series

The following graph illustrates the temperature frequency plot for the existing building based on the projected climate data for the 2080's time series:

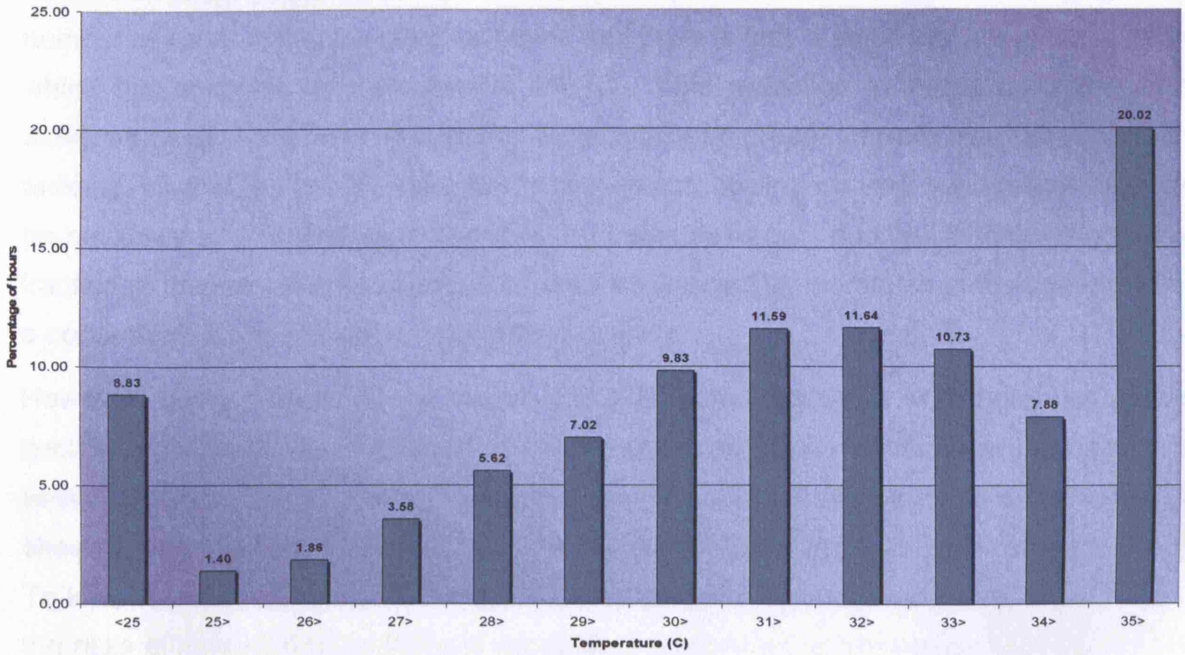


Figure 47: Temperature frequency plot in existing building (without passive cooling strategies) during the summer period of projected year 2080

The next graph illustrates the temperature frequency plot for the modified building (with application of passive strategies) based on the 2080's projected climate data:

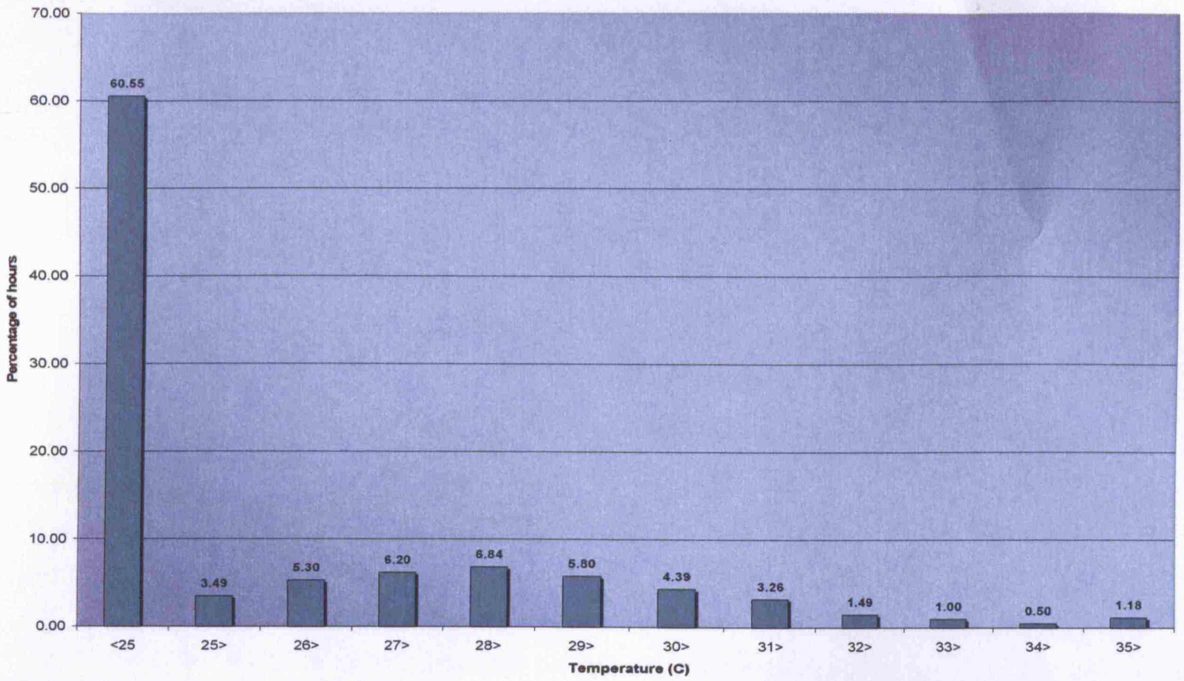


Figure 48: Temperature frequency plot in modified building (with passive cooling strategies) during the summer period of projected year 2080

The frequency plots clearly show that the inclusion of adequate natural ventilation and shading does cause a considerable improvement in internal temperatures in the care home during the summer months. In the 2020's and even in the 2050's timeseries, the plots are seen to be left-skewed, signifying that internal temperatures lie below 25 °C for a significant number of hours during the summer period and there is only a small fraction of hours during which the temperature goes beyond 30 °C. This reduction in temperature has been achieved by applying natural ventilation techniques and proper insulation and shading to the building, so that the energy used due to mechanical cooling on very hot summer days can be cut down to a more reasonable level by being used only during the remaining smaller fraction of time, when it is necessary to keep the internal temperatures in the building within a comfortable limits to prevent heat-related deaths.

However, going further into the future, it can be noted that even with the aid of passive cooling techniques, the frequency of occurrence of high internal temperatures cannot be easily avoided. In the 2080's timeseries, the temperature distribution is seen to be less skewed, and the frequency of occurrence of higher temperatures is seen to be increased. To keep the internal temperatures at a reasonable level within the care home and to reduce the risks of heat-related mortality, it is therefore expected that mechanical cooling will have to be used in all rooms, or at least one room, which can be referred to as a 'cool' room, i.e., on exceptionally hot days, this room would be kept within safe temperature limits by mechanical means of cooling and residents of the care home can be gathered in that room during those hot spells.

8. Discussions and conclusion

There is now clear evidence of climatic change, and the fact that hot weather induces health risks, especially in older people, since they are more susceptible to heat. In the United Kingdom the most rapidly growing segment is that of elderly aged 85 years and over (Valins, 1988), and the population of elderly people in the UK is deemed to increase in the future years. The quality of life in residential homes and their architectural design has been a striking feature of the French heat wave crisis (Ogg, 2005). It is therefore important that care homes for the elderly are suitably designed and maintained to ensure that the environmental conditions prevailing inside the buildings are within safe limits to prevent heat-related deaths from occurring during heat-waves which, according to current studies on climate change, are believed to be occurring more frequently and with more severity in the years to come. Moreover, heat-related illnesses and deaths are a greater problem in cities than in suburban or rural areas, because the combined effect of high temperature and high humidity is more intense in the centres of urban areas (Wilhelmi *et al.,* 2004). With the rapid growth of urban population and the urban heat island effect, coupled with a potential increase in the frequency and duration of heat waves due to climate change, it is imperative to find effective means of mitigating the impacts of heat waves, especially in urban areas.

The study in this report focuses essentially on the ways in which climate change will affect the internal conditions in care homes in the UK in the future, and how the building envelope and structure might be adapted to climate change in order to reduce the risks of heat-related mortality in this type of building. Estimates of future climatic conditions have been made, based on the UKCIP02 Medium-High climate change scenarios by deriving projected hourly values of temperature, humidity, irradiation, wind speed, etc., using a set of algorithms to morph the existing climatic data. Results showed that in the 2080's the mean *daily* temperature is estimated to be about 5-6 degrees higher during peak summer days, with regards to the 1989 standard CIBSE Dry Summer Year (DSY) climate. The changes in some of the climatic variables (T_{max}, T_{min}, solar irradiance, etc.) are also illustrated in Section 3.8 of this report. It clearly shows that a considerable increase in temperature will occur in the future years and, consequently it will be increasingly difficult to keep the internal conditions within buildings within comfortable limits without relying on mechanical means of cooling. However, if the right strategies are applied and the building form is carefully designed so that heat gains in the summer are minimised, the internal temperatures can be substantially lowered and kept within safe limits for longer periods of time. Air-conditioning can then be used only when necessary, if natural means of cooling are not sufficient enough.

As can be seen from the results of the simulations, the application of passive cooling strategies and the proper use of shading and insulation significantly reduce the number of hours during which the temperature goes beyond the safe temperature limits. However, this becomes increasingly challenging looking further into the future, especially in the 2080's. The results show that, generally, the application of passive strategies, such as natural ventilation, night purge, in combination with proper shading, insulation and thermal mass, was effective in keeping the internal temperatures below threshold temperatures for a significant period of time, in all timeseries, however becoming less effective in the 2080's. As a consequence, some mechanical cooling will be inevitable to keep the temperature within safe limits in the future.

From the results of this study, the application of proper shading to the building was found to have a considerable effect on reducing internal temperature, by reducing solar heat gains during the summer. With the use of shading techniques such as movable louvers, the amount of solar gains can be controlled in summer and winter so that the building can perform adequately in both seasons. In addition, internal heat gains should be kept to a minimum by reducing or controlling the use of lights, using low-energy lighting as far as possible, and controlling the use of heat-producing appliances in rooms where the temperature needs to be kept below the threshold temperature. The use of thermal mass in combination with night ventilation also proved to be an effective way of reducing internal temperatures in the building, by allowing the spaces to be purged with cooler air at night so as to maximise the heat absorption capacity of the building fabric.

Therefore, in order to provide acceptable internal conditions without incurring large increases in energy use, good passive design strategies and techniques should be applied at the construction or refurbishment stage, and the use of mechanical cooling should be used as a supplement only when needed. It has to be kept in mind however, that not all buildings can be easily modified to include the above-mentioned strategies; in this case, the preferable solution would be demolition and reconstruction of the building. In some other cases, the inclusion of passive strategies might not be desirable, for instance because of aesthetic or economical reasons, thereby making mechanical cooling a necessity. It should however be kept in mind that increased use of mechanical cooling systems will slow down the efforts to reduce greenhouse gas emissions and to limit climate change. Investigation and research into low-energy mechanical systems is therefore essential, as well as the setting up of structured guidance to building owners, which would specify the potential solutions, costs and the timescales over which they should be introduced, so as to help in the decision of the most appropriate adaptation strategies to be used in the buildings.

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Appendix A.1 – Summary of internal temperatures in the *existing* building in the three time-series: 2020's, 2050's and 2080's

FIRST FLOOR LIVING ROOM (existing model)

	2020 time series			2050 time series			2080 time series		
Day	Ave ext. Temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum
152	11.27	22.61	27.38	11.97	22.98	27.93	13.68	23.96	29.31
153	12.10	22.27	26.04	12.85	22.64	26.54	14.58	23.67	27.82
154	11.57	22.06	26.83	12.28	22.41	27.36	14.01	23.39	28.69
155	11.93	22.01	25.53	12.67	22.40	26.02	14.40	23.49	27.29
156	12.54	21.98	25.95	13.33	22.49	26.50	15.05	23.71	27.83
157	11.41	21.55	25.40	12.11	21.91	25.97	13.83	22.87	27.34
158	13.47	21.75	24.72	14.32	22.19	25.25	16.05	23.29	26.54
159	12.38	21.77	25.55	13.15	22.27	26.16	14.88	23.44	27.50
160	15.49	22.92	25.76	16.50	23.68	26.46	18.23	25.10	28.19
161	17.66	23.95	27.79	18.84	24.81	28.63	20.56	26.34	30.15
162	18.61	25.06	28.20	19.86	26.15	29.73	21.59	27.76	31.51
163	22.99	27.79	31.65	24.58	29.07	33.21	26.30	30.76	35.08
164	23.43	28.95	33.28	25.06	30.29	33.96	26.78	32.00	35.73
165	23.02	29.10	32.80	24.61	30.58	34.16	26.34	32.30	35.90
166	22.29	29.41	32.87	23.83	30.94	34.28	25.55	32.68	36.03
167	21.84	29.32	33.33	23.34	30.87	34.80	25.07	32.62	36.58
168	21.96	29.74	33.36	23.47	31.34	34.88	25.20	33.10	36.66
169	21.44	29.84	32.91	22.91	31.42	34.43	24.64	33.23	36.20
170	22.36	30.59	33.95	23.90	32.25	35.80	25.62	34.05	37.71
171	24.72	31.74	35.25	26.44	33.50	37.35	28.17	35.31	39.19
172	19.84	29.46	34.11	21.18	31.07	35.74	22.91	32.87	37.57
173	17.13	27.22	32.04	18.26	28.65	33.53	19.99	30.46	35.34
174	20.14	28.53	31.48	21.50	30.07	33.19	23.23	31.89	35.12
175	20.27	28.96	32.05	21.65	30.53	33.55	23.38	32.36	35.39
176	20.52	29.61	32.42	21.92	31.16	34.10	23.64	33.08	36.17
177	19.18	30.60	34.95	20.47	32.11	36.55	22.20	34.00	38.48
178	16.70	28.49	33.37	17.81	29.87	34.86	19.53	31.75	36.74
179	15.51	28.39	31.67	16.52	29.72	33.01	18.25	31.55	34.85
180	15.96	25.36	29.34	17.01	26.40	30.59	18.73	27.97	32.39
181	17.20	25.74	29.76	18.35	26.94	30.96	20.07	28.68	32.69
182	18.84	25.93	30.39	20.01	27.14	31.69	22.04	29.02	33.62
183	17.02	25.05	29.16	18.01	26.26	30.36	20.05	28.21	32.27
184	19.03	26.36	29.24	20.21	27.69	30.49	22.25	29.70	32.45
185	20.69	29.13	35.25	22.02	30.50	36.79	24.07	32.56	38.99
186	22.86	30.64	35.96	24.40	32.09	37.56	26.44	34.18	39.75
187	24.91	30.95	35.19	26.64	32.54	36.87	28.68	34.62	39.01
188	20.40	27.82	32.59	21.70	29.28	34.10	23.75	31.32	36.14
189	20.14	27.40	31.98	21.42	28.86	33.45	23.46	30.90	35.52
190	17.48	25.43	30.27	18.52	26.67	31.65	20.56	28.69	33.68
191	20.62	27.00	30.19	21.94	28.40	31.50	23.99	30.44	33.56

FIRST FLOOR LIVING ROOM

	2020 time series			2050 time series			2080 time series		
Day	Ave ext. Temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum
192	22.28	28.51	31.53	23.77	30.05	33.28	25.81	32.13	35.50
193	19.96	27.70	32.13	21.23	29.20	33.64	23.27	31.29	35.75
194	20.17	28.26	31.41	21.46	29.81	32.90	23.50	31.93	35.10
195	18.52	27.46	31.89	19.64	28.94	33.38	21.69	31.07	35.55
196	21.63	29.07	32.38	23.05	30.70	34.39	25.10	32.84	36.55
197	20.47	28.41	32.30	21.78	29.98	33.84	23.82	32.12	36.01
198	23.03	29.83	32.66	24.58	31.50	34.24	26.62	33.64	36.41
199	21.11	29.37	32.88	22.48	31.03	34.50	24.52	33.18	36.65
200	21.70	30.03	32.83	23.12	31.74	34.56	25.17	33.90	36.82
201	23.79	31.47	34.92	25.41	33.29	36.94	27.45	35.47	39.26
202	25.44	33.55	39.90	27.22	35.38	41.91	29.26	37.60	44.27
203	28.05	34.11	37.70	30.07	36.15	40.23	32.12	38.32	42.38
204	27.02	34.14	36.96	28.94	36.19	38.88	30.99	38.37	41.09
205	25.81	33.53	37.33	27.62	35.56	39.32	29.67	37.72	41.52
206	24.90	33.02	36.57	26.63	35.01	38.52	28.68	37.16	40.71
207	23.03	31.72	36.04	24.58	33.60	37.95	26.63	35.74	40.12
209	21.50	30.94	34.56	22.91	32.71	36.33	24.96	34.85	38.51
210	21.42	29.97	34.10	22.82	31.72	35.83	24.87	33.84	37.99
211	18.23	27.61	32.84	19.33	29.07	34.49	21.38	31.20	36.62
212	15.81	25.67	31.14	16.68	26.95	32.61	18.73	29.02	34.74
213	17.45	26.08	29.37	18.78	27.56	30.73	20.97	29.73	32.85
214	18.70	26.37	30.19	20.12	27.95	31.68	22.33	30.14	33.89
215	21.54	27.67	31.08	23.23	29.40	32.69	25.44	31.62	34.93
216	20.38	28.09	30.84	21.96	29.87	32.82	24.17	32.12	35.19
217	21.35	29.22	32.19	23.02	31.11	34.48	25.23	33.38	36.78
218	23.57	30.57	34.05	25.44	32.57	36.50	27.66	34.86	38.75
219	22.33	30.55	33.86	24.09	32.54	35.77	26.30	34.82	38.09
220	22.10	30.10	33.50	23.84	32.06	35.40	26.05	34.32	37.70
221	22.25	31.61	36.45	24.00	33.52	38.47	26.22	35.80	40.83
222	18.99	27.52	32.56	20.43	29.22	34.37	22.65	31.47	36.61
223	20.04	29.55	35.94	21.58	31.31	37.88	23.79	33.57	40.29
224	20.04	29.43	33.17	21.59	31.24	35.11	23.80	33.53	37.43
225	19.16	29.97	34.79	20.62	31.72	36.63	22.84	33.99	38.99
226	20.68	30.20	34.24	22.29	31.93	36.06	24.50	34.20	38.38
227	21.24	30.85	35.44	22.90	32.60	37.29	25.12	34.88	39.64
228	20.52	30.51	35.58	22.11	32.31	37.48	24.32	34.58	39.85
229	18.21	28.84	32.52	19.58	30.61	34.26	21.79	32.86	36.55
230	17.93	28.15	31.41	19.28	29.91	33.10	21.49	32.18	35.38
231	20.89	29.10	32.02	22.51	30.96	34.11	24.72	33.26	36.55
232	22.31	31.18	38.30	24.07	33.13	40.48	26.28	35.48	43.01
233	21.72	30.34	33.46	23.43	32.32	35.35	25.64	34.65	37.69
234	19.37	29.42	33.37	20.85	31.31	35.26	23.06	33.61	37.62
235	19.07	29.37	32.69	20.53	31.26	34.92	22.74	33.56	37.17

FIRST FLOOR LIVING ROOM

	2020 time series			2050 time series			2080 time series		
Day	Ave ext. Temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum
208	21.06	30.71	34.75	22.42	32.51	36.56	24.47	34.63	38.72
236	19.81	29.78	34.70	21.33	31.69	36.80	23.54	34.01	39.20
237	18.47	27.18	32.78	19.87	28.86	34.63	22.09	31.14	36.96
238	18.24	26.42	30.75	19.62	28.08	32.41	21.83	30.32	34.70
239	16.70	25.98	29.58	17.94	27.59	31.17	20.15	29.83	33.42
240	15.67	25.31	28.66	16.80	26.86	30.19	19.02	29.13	32.44
241	17.24	25.12	29.04	18.52	26.64	30.58	20.73	28.90	32.86
242	20.83	27.56	34.68	22.45	29.26	36.59	24.66	31.53	39.06
243	17.41	25.89	30.43	18.71	27.49	32.05	20.92	29.76	34.35

Appendix A.2 – Summary of internal temperatures in the modified building (with inclusion of passive strategies) in the three time-series: 2020's, 2050's and 2080's

FIRST FLOOR LIVING ROOM

	2020 time series			2050 time series			2080 time series		
Day	Ave ext. Temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum
152	11.27	17.09	17.43	11.97	17.07	17.35	13.68	17.17	17.57
153	12.10	16.97	17.58	12.85	17.03	17.84	14.58	17.60	19.26
154	11.57	16.95	17.41	12.28	16.95	17.68	14.01	17.35	19.00
155	11.93	16.81	17.49	12.67	16.89	18.32	14.40	17.57	20.02
156	12.54	17.05	18.76	13.33	17.31	19.67	15.05	18.21	21.30
157	11.41	16.93	17.51	12.11	16.99	17.43	13.83	17.09	17.31
158	13.47	16.93	17.62	14.32	17.11	18.55	16.05	17.76	20.24
159	12.38	16.95	17.51	13.15	17.02	18.33	14.88	17.46	20.02
160	15.49	17.80	20.47	16.50	18.33	21.68	18.23	19.38	23.35
161	17.66	18.95	22.34	18.84	19.70	23.75	20.56	20.88	25.53
162	18.61	20.03	24.40	19.86	20.90	25.76	21.59	21.79	26.95
163	22.99	22.80	28.73	24.58	23.16	28.00	26.30	24.57	29.29
164	23.43	23.90	29.84	25.06	24.44	29.35	26.78	25.98	30.74
165	23.02	23.89	29.63	24.61	24.82	29.73	26.34	26.59	31.27
166	22.29	23.04	30.00	23.83	24.02	30.24	25.55	25.97	31.91
167	21.84	23.04	29.76	23.34	23.94	29.93	25.07	25.71	31.63
168	21.96	23.01	30.38	23.47	23.88	30.19	25.20	25.70	31.90
169	21.44	22.64	30.01	22.91	23.27	29.61	24.64	24.98	31.29
170	22.36	22.99	30.48	23.90	23.48	29.72	25.62	25.24	31.36
171	24.72	24.83	31.54	26.44	25.33	30.68	28.17	27.11	32.37
172	19.84	20.33	23.98	21.18	21.99	28.07	22.91	24.53	30.93
173	17.13	18.32	20.69	18.26	18.97	21.98	19.99	20.31	23.70
174	20.14	21.33	28.09	21.50	21.68	27.28	23.23	23.12	28.87
175	20.27	21.44	28.35	21.65	22.03	27.60	23.38	23.66	29.26
176	20.52	21.70	29.34	21.92	22.09	28.43	23.64	23.58	30.02
177	19.18	19.87	23.74	20.47	20.97	26.38	22.20	22.93	28.78
178	16.70	17.76	20.18	17.81	18.41	21.52	19.53	19.81	23.25
179	15.51	17.42	19.84	16.52	18.05	21.13	18.25	19.23	22.85
180	15.96	17.70	20.09	17.01	18.20	21.25	18.73	19.38	22.94
181	17.20	18.64	22.03	18.35	19.42	23.46	20.07	20.71	25.69
182	18.84	19.14	22.74	20.01	20.17	24.20	22.04	22.26	26.70
183	17.02	18.45	20.98	18.01	19.13	22.22	20.05	20.60	24.20
184	19.03	20.37	26.32	20.21	20.87	26.09	22.25	22.42	27.82
185	20.69	21.59	28.02	22.02	22.08	27.45	24.07	23.60	29.00
186	22.86	22.86	28.88	24.40	23.31	28.58	26.44	25.10	30.30
187	24.91	24.42	29.48	26.64	25.27	29.94	28.68	27.12	31.73
188	20.40	20.94	23.29	21.70	22.19	25.32	23.75	25.53	30.44
189	20.14	20.62	26.39	21.42	22.30	27.92	23.46	24.67	30.24
190	17.48	18.04	19.80	18.52	18.89	20.98	20.56	20.91	23.03
191	20.62	21.19	26.12	21.94	21.89	26.71	23.99	23.92	28.80

FIRST FLOOR LIVING ROOM

Day	2020 time series			2050 time series			2080 time series		
	Ave ext. Temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum
192	22.28	22.85	29.17	23.77	23.59	28.67	25.81	25.94	30.81
193	19.96	20.45	23.50	21.23	21.76	26.32	23.27	24.75	30.30
194	20.17	21.33	28.83	21.46	22.02	28.19	23.50	24.14	30.41
195	18.52	19.79	23.81	19.64	20.69	26.45	21.69	22.38	28.61
196	21.63	22.25	29.05	23.05	22.49	28.14	25.10	24.18	29.99
197	20.47	21.16	28.01	21.78	21.98	27.72	23.82	24.16	29.82
198	23.03	23.02	29.04	24.58	23.58	28.89	26.62	25.74	30.93
199	21.11	22.28	29.66	22.48	23.27	29.09	24.52	25.58	31.21
200	21.70	22.63	30.00	23.12	23.08	29.29	25.17	25.37	31.43
201	23.79	24.16	31.25	25.41	24.72	30.49	27.45	27.22	32.60
202	25.44	25.47	32.22	27.22	26.28	31.73	29.26	28.80	33.99
203	28.05	27.62	33.55	30.07	28.53	33.39	32.12	31.67	35.92
204	27.02	28.00	34.16	28.94	29.03	33.95	30.99	32.81	36.85
205	25.81	27.71	33.63	27.62	29.61	34.30	29.67	33.37	37.23
206	24.90	26.54	32.80	26.63	28.08	33.58	28.68	32.72	37.01
207	23.03	24.79	31.29	24.58	26.65	32.26	26.63	31.55	35.97
208	21.06	22.83	30.39	22.42	23.93	30.71	24.47	27.32	33.92
209	21.50	22.76	29.95	22.91	23.70	30.03	24.96	26.94	32.97
210	21.42	22.34	28.92	22.82	23.29	29.41	24.87	25.95	32.12
211	18.23	18.72	20.31	19.33	19.74	21.49	21.38	21.76	23.57
212	15.81	17.80	19.97	16.68	18.27	21.17	18.73	19.51	23.21
213	17.45	19.43	23.28	18.78	20.16	25.13	20.97	21.69	27.31
214	18.70	20.06	24.61	20.12	21.17	26.17	22.33	22.70	27.95
215	21.54	21.86	27.20	23.23	22.68	27.72	25.44	24.61	29.51
216	20.38	21.48	28.52	21.96	22.07	27.98	24.17	23.95	29.91
217	21.35	22.28	29.38	23.02	22.76	28.56	25.23	24.74	30.52
218	23.57	23.85	30.10	25.44	24.57	29.87	27.66	26.84	31.94
219	22.33	23.09	29.76	24.09	24.29	30.00	26.30	26.79	32.24
220	22.10	22.91	29.23	23.84	24.18	29.72	26.05	26.92	32.15
221	22.25	23.08	29.32	24.00	24.51	29.90	26.22	27.24	32.21
222	18.99	19.64	21.87	20.43	20.99	23.50	22.65	23.59	27.86
223	20.04	20.58	27.81	21.58	21.76	27.71	23.79	24.13	30.07
224	20.04	20.57	27.80	21.59	22.11	28.10	23.80	24.50	30.41
225	19.16	19.83	23.17	20.62	21.07	25.65	22.84	23.71	29.18
226	20.68	20.92	26.06	22.29	22.49	27.09	24.50	25.14	29.85
227	21.24	21.44	26.54	22.90	23.31	28.37	25.12	25.91	30.80
228	20.52	20.87	26.60	22.11	22.91	28.54	24.32	25.61	30.99
229	18.21	19.21	23.60	19.58	20.37	26.55	21.79	22.65	29.10
230	17.93	19.78	26.27	19.28	20.77	26.62	21.49	22.41	28.71
231	20.89	21.87	27.92	22.51	22.27	27.70	24.72	23.90	29.58
232	22.31	22.74	29.94	24.07	23.37	29.00	26.28	25.56	31.02
233	21.72	22.68	30.26	23.43	23.61	29.47	25.64	26.27	31.78

FIRST FLOOR LIVING ROOM

	2020 time series			2050 time series			2080 time series		
Day	Ave ext. Temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum	Ave ext temp	Daily Average	Daily Maximum
234	19.37	20.57	27.12	20.85	21.76	28.03	23.06	23.94	30.28
235	19.07	20.78	28.54	20.53	21.43	27.98	22.74	23.25	30.02
236	19.81	21.04	28.23	21.33	21.65	28.01	23.54	23.41	29.84
237	18.47	19.06	23.35	19.87	20.33	25.71	22.09	23.04	28.95
238	18.24	18.93	24.01	19.62	20.05	25.49	21.83	22.37	27.89
239	16.70	17.88	20.25	17.94	18.61	21.75	20.15	20.41	23.96
240	15.67	18.24	21.43	16.80	18.87	22.84	19.02	20.21	26.12
241	17.24	18.66	21.13	18.52	19.60	22.71	20.73	21.24	25.21
242	20.83	20.98	27.69	22.45	22.00	27.07	24.66	24.25	29.09
243	17.41	18.59	21.65	18.71	19.52	23.19	20.92	21.63	27.58